Biomass Consumption and Assessment of Cropping & Yield Patterns of Various Components under Different Traditional Agroforestry Systems, Across an Altitudinal Gradient in Kumaun Region of Central Himalayas

THESIS

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BY

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Under the Supervision and Guidance

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Certificate

Certified that **Mr. Kundan Singh** has carried out the research work entitled **"Biomass Consumption and Assessment of Cropping & Yield Patterns of Various Components under Different Traditional Agroforestry Systems, Across an Altitudinal Gradient in Kumaun Region of Central Himalayas"**, under my supervision and guidance.

It is further certified that the research work in this thesis being submitted by Mr. Singh for the degree of **Doctor of Philosophy in Agroforestry**, embodies original research work, carried out within the required period stipulated by Institute of Agriculture Sciences Bundelkhand University, Jhansi.

Date : 20th May 2009

Place: Jhansi

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Supervisor

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Place: Jhansi

(Kundan Singh)

Date : 20.05.2009

CONTENTS

ABBREVIATIONS USED

AS	Agrisilvicultural
AH	Agrihorticultural
AHS	Agrihortisilvicultural
AFS	Agroforestry Systems
Control	Without Integration of Trees
MJ	Megajule
kg	Kilogram
g	Grammes
yr.	Year
Rs.	Rupees
q	Quintal
pH	Potentiality of Hydrogen Ion
O.C.	Organic Carbon
N	Nitrogen
P	Phosphorus
K	Potassium
ha	Hectares
m asl	Mean Above Sea Level
lt.	Litre
m	Metre
cm	Centimeter
km	Kilometer
d	Distance
hrs	Hours
LPG	Liquid Petroleum Gas
(±)SD	Standard Deviation
CD	Critical Difference
ICAR	Indian Council of Agricultural Research
ICRAF	International Council for Research in Agroforestry
SP	Silvi-pastoral

Centre

INTRODUCTION

In combined production systems, agriculture, livestock production, forestry, and combinations thereof are practiced on the same piece of land, either in rotation, simultaneously, or spatially. Such combinations, also called "agroforestry", can involve agricultural crop production or animal husbandry, within which trees play a significant role in forage production in arid and semi arid regions. Most of trees are drought resistant; they are still able to provide feed to livestock when the crops fail, as frequent droughts are a common phenomenon in arid and semi arid regions. The problem of feed shortage is major one in India. The avaliable agroforestry technologies have shown promise in increasing fodder yields, agroforestry can be an appropriate technology in indian situation where there is land scarcity, plenty of labour but less productive and scare capital .Incorporation of multipurpose forage yielding trees and shrubs into such systems is very important. Such low ~~input~~ input land use systems are expected to be economically sustainable. Thus agroforestry have a very important place in the life of man in arid regions of India, as they are directly related to the livelihood of inhabitants and also provide the important service of climate moderation in many forms in an inhospitable environment. Agroforestry is a sustainable land use system that maintain or increases total yield by combining food (annual) crops with tree (perennial) crops and /or livestock on the same unit of land either alternating or at the same time, using management practices that suit the social and cultural characteristics of the society and the economic and ecological conditions of the area. The important component of this land use system are the trees which when combined with crops, yield certain important environmental benefits such as reduction of pressure of forestry, efficient recycling of nutrients, reduction in nutrient leaching and soil erosion, improvement of microclimate, etc. (Bene *et al.*, 1977; King, 1978; Bhatt, 2003; Nazir *et al.*, 2007; Singh and Sharma, 2007; Sood and Mitchell, 2009).

Agroforestry can be used to diversify and intensify farming systems through integration of indigenous trees-crops: It has many fold advantages over the traditional farming systems in terms of sustainability and profitability. Agroforestry based farming in agroecosystem function is one of the keystones of sustainability. Thus sustainability involves a symbiosis between the properties of

the ecosystem and the management activities that results in no declining and relatively stable outcomes. International Centre for Research in Agroforestry (Raintree, 1997 and Bellow *et al.,* 2008) foresees that agroforestry can contribute to human welfare and environment resilience, with improved systems providing:

- Tree products that both increase the nutritional security and generate cash income for poverty alleviation.
- Services that support and enhance ecosystem function.

The relevant services of trees are those that increase the crop yields (N_2 fixation, increased soil organic matter, nutrient cycling, soil conservation, etc.), create environment resilience (nich diversification, food web complexity, carbon sequence, etc.), and provide scilal benefits (boundary delineation, shade, etc.). Bringing the new ideas about agroforestry and about domestication together provides one with a new paradigm for sustainable land-use development that focuses on two aspects of biodiversity:

- Diversifying agroecosystems, ~~and~~
- Capturing and enhancing intraspecific diversity (Bhatt, 2003; Das and Chaturvedi (2008); McGraw, *et al.,* 2008; Schoeneberger, 2009; Agarwal, and Goyal, 2009; Sood and Mitchell 2009)

In hill agroecosystems, agroforestry plays an important role in sustainability, resource conservation and food security. This land use system is particularly suitable for resource poor marginal land and even for wastelands. Large-scale indiscriminate cutting of trees has deteriorated the environment considerably in Himalayan zone of Kumaun Himalaya. Enormous loss of soil and water, recurrent floods and desertification are some of the perceptible indication of degraded environment, which has resulted in its low productivity and sustainability (Singh, 1984).

Foresters in the past have seen agroforestry mainly in terms of improving the supply of forest products; agriculturists have seen it as a logical extension of traditional intercropping practices, as an aid to soil conservation measures and as plantation agriculture, such as tea plantations. Soil conservation specialists

see agroforestry as a major tool in the maintenance of soil productivity, and ecologists seek the increase in diversity that moving away from monocultures can bring. In rural development, the improvement of land use systems and thus of rural incomes and well being is a primary objective (Wood, 1998). In broader sense, the major function of agroforestry is associated with sustainability for the farmer, stability of resources, production and income, and minimization of risk. The objective of sustainability is probably the most important function of such kind of land use systems (Maikhuri and Rao, 1997; Bhatt, 2003; Banful, *et al.*, 2007; Bellow *et al.*, 2008; Meghan *et al.*, 2008; Houx, *et al.*, 2008;).

The woody perennials include trees, shrubs, bushes, palms, bamboos, rattans, etc., which in the agroforestry context, are often referred to as multipurpose trees and shrubs (MPTS). Land use system can be large, e.g., a watershed or catchments, or small; the most usual and important until is the individual farm. The word "deliberate" is also significant- a few trees remaining during the process of land clearance for agriculture is not agroforestry. To qualify as agroforestry, a system requires that the farmer actively promote the woody perennials for a particular purpose, or purposes, on the farm (Wood, 1998). Kumaun hills have strong tradition to cultivate various multiporpose tree and shrub species in and around agricultural fields. As many as 42 multiporpose tree/ shrub species have been reported, which are extensively cultivated in rainfed agroecosystem of Kumaun hills to meet out fuel, fodder, fibre and timber requirements (Singh, 1984). But due to substantial increase in human and bovine population on the one hand and decreasing forests on the other, people of the region are facing acute shortage of fuel, fodder and timber (Negi *et al.*, 1999). Although, India has made massive investments in agriculture and has achieved spectacular success on the food but the scarcity of fuelwood, fodder and other forest produce still prevails particularly in Central Himalayan agroclimatic region. It is now realized that not only do the current land use systems (agriculture, forest and animal husbandry) need more intensive research and development effort, but alternate traditional systems, e.g., agroforestry, which have been hitherto overlooked, also need to be strengthened for long term sustainable production. This is much more true of hilly region, which have following special characteristics:

(i) Less developed compared to plains,

(ii) More densely populated than many other hilly regions of the world (Tejwani, 1984),

(iii) Fragile due to steep topography (Himalaya being more fragile than the Western Ghats (Gupta, 1975),

(iv) Difficulty of access, and

(v) Much more rural and agrarian than the plains (Tejwani, 1993).

Traditional agroforestry systems of the Himalayan region are closely interlinked with the livestock, forest and rangeland and have prime importance for the subsistence of local communities. Agro-ecosystems are essentially man made ecosystems and reflect evolution of human culture, they are geared to meet the basic human needs of food, fodder, fibre, fuel, fertilizer, timber, fruit and medicine as well as providing economic benefits through commodity crops (Negi *et al.,* 1997 and Meghan *et al.,* 2008). Agroforestry land use, covering 20% of the total geographical area of the Indian Himalaya, is distributed as patches in the matrix of forests covering 52% area (Nautiyal *et al.,* 1998). According to one estimate, in Kumaun hills, there must be 66% forest just only to make ecological balance. But there is only 24.9% of the forest, which comprise only 4.1% dense forest. On the other hand, there is average requirement of 1.49 kg/person/day fuelwood (Singh, 1984) and 40-60 kg of fodder/family/day (Reynolds and Nautiyal, 1987). Thus, to maintain ecological balance and to fulfil daily needs of rural folk on the other, agroforestry farming need to be strengthened (Chauhan *et al.*, 2001 and Bhatt, 2003).

The Kumaun Himalaya has a long history of subsistence economy, with agriculture being the core component, in which over 80% of the people are involved. Realizing the great variations in the altitude, topography, climate, forest resources, and availability of irrigation water, and socio-economic and cultural factors variety of land use pattern exists in the region. Broadly, three basic farming systems have been identified for the Central Himalaya, of which this region is a part. All the systems are livestock based, and form a spectrum of economic activity ranging from nomadism to settled agriculture (Singh *et al.*, 1984). Settled agriculture which is a mixed crop livestock farming system predominates across a vast area between 300 m and 2500 m asl on terraced agricultural fields, except in narrow strip of foot hills where these are flat. The terraces are carved out from the mountain slopes, sometimes greater than 50%.

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The greater part of the agriculture is practiced under rainfed conditions (Negi, 1992).

Traditionally, four cropping systems are practiced in Kumaun hills, which include a kitchen garden around the homestead in which vegetables and some fruits trees are grown for home consumption; an integrated land cropping system in which rice and wheat are the main crops; an upland or non irrigated cropping system, dominantly occupied by millets and pulses, and a summer camp cropping system mainly devoted to pseudo cereals (amaranth and buck-wheat) and beans (mainly kidney beans) (Singh, 1996). However, the traditional cropping system of the region basically consists of summer and winter crops. Paddy, finger millet, hog-millet, foxtail millet, barnyard millet, maize and a variety of pulses are the main components of the *kharif* season, while wheat, mustard, lentil, barley, and peas are the main crops of the *rabi* season. Mixed cropping from 2-6 crops in a single field is practiced on rainfed lands. In addition, paddy, barnyard millet, finger millet, and amaranth are the *kharif* crops, occupying an area of about 40% of agriculture and practiced under rainfed conditions (Semwal and Maikhuri, 1996). According to one estimate, only around 10% land is under irrigation in the Central Himalaya (Ralhan *et al.*, 1992). In the valleys, paddy is grown as monoculture and crop rotations are practiced on both unirrigated and irrigated lands. Animal husbandry plays a crucial link in mountain agroecosystem, which includes cow, bullock and buffaloes. The traditional agroecosystem of the region is mainly operated by animal (bullock) power and human labour in which women play a crucial role (Gairola and Todaria, 1997). Important agroforestry tree species of the area include *Albizia lebbek, Bauhinia* spp., *Boehmeria rugulosa, Celtis australis, Ficus* spp., *Grewia optiva, Mallotus philippensis, Melia azedarach, Morus* spp., *Ougeinia oojeinensis* and *Toona ciliata.* Important fruit trees were *Artocarpus heterophyllus, Carica papaya, Citrus spp., Juglans regia, Litchi chinensis, Mangifera indica, Prunus* spp., *Psidium guajava, Musa paradisica, Pyrus* spp. etc (Bhatt and Todaria, 1992; Bhatt and Verma, 2002; Singh, 1982). However, the poor agriculture production from this region has an adverse impact on socio-economic conditions of the farmers and, therefore, economy is based on money orders. It involves temporary emigration of a significant portion of male population to other areas and sending back the parts of their earnings to the members left in villages for the import a food

(Swarup, 1993; Singh and Sharma, 2007; Saha *et al.*, 2007; Das and Chaturvedi 2008).

So far various workers have reported the agroforestry systems of the region (Semwal and Maikhuri, 1996; Nautiyal *et al.*, 1998; Singh *et al.*, 1997; Negi *et al.*, 1997; Negi *et al.,* 1999; Bhatt and Todaria 1990a, 1990b, 1990c; Bhatt and Todaria, 1991; Bhatt *et al.,* 1995; Kaletha *et al.,* 1996a, 1996b, 1996c; Todaria and Bhatt, 1992; Bhatt and Badoni, 1995 Nazir *et al.*, 2007; Singh and Sharma, 2007; Saha *et al.*, 2007; Escobar *et al.*, 2007; Lorenzo *et al.*, 2007; Sharrow, 2007; Banful, *et al.*, 2007; Bellow *et al.,* 2008; Meghan *et al.,* 2008; Houx, *et al.,* 2008; Fernandez *et al.,* 2008; Staley *et al.,* 2008; Bayala *et al.,* 2008; Burner and Belesky, 2008; Das and Chaturvedi 2008; McGraw, *et al.,* 2008; Schoeneberger, 2009; Agarwal and Goyal, 2009; Sood and Mitchell 2009) however, no information is available on the functioning of traditional agroforestry systems of Kumaun Himalaya, hence in the present thesis an attempt have been made to understand the structure and functioning of traditional agroforestry systems of Kumaun Himalaya along an altitudinal gradient taking into consideration the following objectives:

1. Identification of important agroforestry systems along an altitudinal gradient.in Kumaun Himalaya.
2. Contribution of agroforestry trees in terms of fuel, fodder and fruit.
3. Assessment of cropping and yield pattern under different agroforestry systems across an altitudinal gradient in terms of energy and monetary as a currency.
4. Assessment of structure and functioning of agroforestry systems across an altitudinal gradient in Kumaun Himalaya.

ABOUT THE REGION

Taking people-forest in the present context of Kumaun Himalaya, the former comprehensively depend on the latter for their subsistence. Cattle rearing, agriculture to fuel and timber requirements of the residents, particularly those living in upper reaches are fulfilled by the forests growing in their vicinity. The principal crops grown are rice, wheat, several kinds of millets, and pulses. Even today, agriculture is mainly for home consumption though a small proportion of the cultivated area is used to grow potatoes, a cash crop. Commercial horticulture is important in localized areas. Irrigated land, known as *talaon* land is mostly confined to valleys and forms less than 10 per cent of the total cultivated area (Anonymous, 1988). Most cultivation is carried out on terraced fields rising from the valley floors and is entirely rainfed. Such lands are known as *upraon*. The *upraon* soils are, by and large, light, shallow, and low in humus content (Singh et al., 1994 and Negi *et al.,* 1997). Fertilizer consumption is less than 5 kg/ ha in most of the districts of Kumaun Himalaya compared to 65 kg/ ha in Uttar Pradesh as a whole (Anonymous, 1988). However, farmyard manure is widely used in summer and winter crops. Two kinds of organic ~~fertilizers~~ manures are used all over the hills. One is leaf mould gathered from the forest floor in broad-leaved forests like oak. The other is made by using dry leaves or pine needles as bedding for cattle. This is ~~mixed with~~ animal dung and urine and ~~fermented,~~ serves as manure (Singh *et al.*, 1984). gets mixed with dung and urine. Simultaneously it is subjected to the process of fermentation. ~~and~~ which turns it into good manure.

A vital function of hill cattle is the production of manure. Hill cows provide very little milk, perhaps half a litter per day on an average. Buffaloes are better milch animals. Bullocks are used for ploughing and goats are kept for meat. The animals are grazed in common lands and forests. Livestock are also stall-fed but cattle-feed rarely purchased. The only fodder crop is *Jau* (barley) and due to the scarcity of cultivable land, does not form a major part of animal diet. The main feeds are straw from agricultural land, leaflets from pine forests, and foliage etc.

~~In addition to this~~ Besides above, the villagers obtain firewood and ~~building~~ timber from forests. Cooking fuel in the rural areas of the hills is still firewood though the use of kerosene, LPG and biogas is on the increase (Anonymous, 1985). Firewood gathered by villagers is mostly deadwood or branches lopped from trees. Felling

for this purpose is rare and usually illicit. But trees are felled for timber and small poles are cut for miscellaneous uses (Singh *et al.*, 1994). In these various ways, rural life in the hills is very closely tied up with the forests. According to estimate, 1 unit energy from agriculture requires 12 energy units from the forest biomass energy (Singh *et al.*, 1997). Further, it has also been estimated that annually a hectare of cultivated land requires 11.5 ton of fodder, 7.4 ton of fuel wood and 3.4 ton of bedding leaves in the Central Himalaya (Singh *et al.*, 1984). Until recent times the agriculture of Kumaun Himalaya was sustainable largely due to a large resource base. However, in recent years, reckless destruction of forests in the name of development, population growth, fragmentation of land holdings, the accelerated soil erosion, etc. have adversely affected the sustainability of the agricultural systems. As a result, the region is left with only about 5% forest having crown cover above 60% (Singh and Singh, 1987). These problems coupled with rapid socio economic changes are leading to ~~ever process of~~ incidence of land abandonment (Negi and Joshi, 1995).

About 9.6% of the total area of Kumaun Himalaya is under agriculture as against 30% in case of the state, i.e., Uttaran~~chal~~khand. Rainfed agriculture is the common feature in the region which is practised on the well terraced slopes. Irrigated land is scanty. Irrigation is done by streams, springs, *Gools* and small canals. The restoring of water on the *khals* (ponds) and its distribution is done by the local people themselves. The farming system is highly integrated, e.g., the soil fertility is maintained via livestock, which also provide the energy for the different agricultural operations (Shah, 1996).

The cultivated land of the village, locally known as *Dhar*, is intensively and extensively cultivated ~~land~~ on the mid slopes of the valleys all over the Kumaun. Each village *Dhar* is divided into *Talli Dhar* (Lower) and *Malli Dhar* (Upper) or some time *Walli Dhar* (Left) and *Palli Dhar* (Right), on the basis of its location with respect to the settlement. On the basis of physical characterstics, slope, soil fertility, irrigation status, productivity and external land features, the revenue department classifies the cultivated land into following types:

- *Talaon* Land- Good quality of land
- *Upraon* Land- Medium quality of land
- *Katil* or *Ukhar* Land- Poor quality of land (Chauniyal, 2001)

The crop rotation is predominant in *Dhar* system of middle Kumaun under temperate and cool temperate zone. In the Tarai and *Bhabar*, there is no *Dhar* system but crops are grown on rotational basis by *rabi* and *kharif* seasons. Thus. evidently the three year crop rotation is predominent in the *Dhar* system. In the *kharif* season, the entire *Dhar* is under crops. The *Dhar* where rice and barnyard millet are grown is locally known as *Aghail Dhar* (March to August) and the one for rice and finger millet, *Dhar* is known as *Pali Dhar* (May to October). Just after *kharif* crops, the *Aghail Dhar* is prepared for *rabi* crops (wheat) in the month of September every year. Besides this, the *Palli Dhar* is left fallow during winter season (November to February). This cycle is continuous under the *Dhar* system according to seasonal changes.

In the nutshell, agriculture production system of the region is not self sufficient and appropriate measures need to be urgently introduced in the region if the sustainability of the traditional agricultural system alongside the natural resource base is to be achieved. One of the effective strategies to this end could be planning agriculture not just as production system but an ecological system as well (Ramakrishnan, 1992). Fortunately, with the renewed global interest in traditional agricultural system, a positive trend in this direction has already set in. Mixed cropping, otherwise practiced by the traditional societies throughout the world, and which is also common in the Grahwal Himalaya, is once again receiving due attention. Alongside being a tool to enhance per unit area production, the traditional agriculture is also significant for controlling weeds and pests and is effective for the recycling of biomass (Altieri, 1995). Infect, mixed cropping along with the strengthening of agroforestry, effective soil and water management, weed control, optimum use of unused biomass, rehabilitation of abandoned and degraded land through technological inputs based on indigenous knowledge of the people offer considerable potential for augmenting the agricultural production of the region on a sustainable basis (Singh *et al.*, 1994; Negi and Joshi, 1995 and Singh & Singh, 1987).

GENERAL DESCRIPTION OF THE STUDY AREA

The study site is located in the Kumaun region of the Central Himalaya. The Kumaun region is spread over a geographical area of 29698 Km^2 (29^0 24' to 30^0 28' N latitude and 69^0 48' to 80^0 6'E longitude).

To record the structure and functioning of traditional agroforestry practices, a preliminary survey was conducted across an altitudinal gradient (ranging for 380 to 2500 m asl). The entire study area was divided into 3 altitudinal zone viz 380 to 500 m asl; 1000 to 1500 m and 2000 to 2500 m. At each altitude, 3 villages were randomly selected for detailed studies. The sites differed in climatic conditions, land use patterns, socio-economic considerations etc. and each represents almost the entire area in which it is located. Some salient features of each site have been mentioned below:

380 to 500 m asl

Kathgogam, Ranibagh and Kotabagh villages of Nainital districts were selected to conduct the study. The area was characterized by sedimentary deposit comprised of shale, sand stone, clays, mudstone, clay stone and boulder conglomerates of the Siwalik formation. The annual average rainfall at this altitude varied from 1250 to 1680 mm; the mean maximum atmospheric temperature from 18.5^{0}C (January) to 38.5^{0}C (June) and the minimum between 10.2^{0}C (January) to 22.0^{0}C (June) **(Table 1).**

The average total number of households in the study sites were 48.3±29.0 with a human population of 349.0±171.6 with 93.0±41.3 adult males, 92.7±43.1 adult females and 163.3±88.1 children (below 12 years of age). The main occupation of the people was agriculture and only about 11.0±4.6% of the adult population was employed. Average livestock polpulation was recorded to be 233.33 with 29.7±28.9 cows, 62.7±45.2 buffaloes, 42.3±25.4 bullocks, 44.3±30.9 calves, 27.3±20.0 goats, 13.3±18.7 sheep's, 3.7±3.2 horses and 10.0±10.8 hens **(Table 2).**

The forest and agroforestry trees were the main sources of fodder, fuelwood, fibre, fruit and bedding for the animals. The majority of livestock stall-fed and were allowed to roam free in the forest for grazing. The principal fodder

and fuel yielding tree species include *Albizia lebbek, Bauhinia variegata, Boehmeria rugulosa, Ficus* spp., *Grewia optiva, leucaena leucocephala, Mallotus phillipensis, Melia azedarach, Morus alba* and *Ougeinia oojeinensis.* Major fruit trees include *Artocarpus heterophylus, Carica* papaya, *Citrus* spp, *Litchi chinensis, Mangifera indica, Prunus persica, Psidium guajava* and *Musa paradisiaca.* Besides, firewood is obtained from *Holoptelea integrifolia, Anogeissus latifolius, Acacia* spp.

The agriculture is practiced strictly along traditional lines in which bullock and human labour plays an important role. The average cultivated land holding in each village was 20.3±14.3 ha, of which 3.2±0.3, 0.34±0.5 and 0.58±0.8 ha was respectively, under agrisilvicultural, agrihorticultural and agrihortisilvicultural practices. Out of 20.3 ha of cultivated land, 48.6±35.8% was irrigated. Agrihortisilvicultural (kitchen gardens), though very small in size was an integral and important component of the village ecosystem. Potato, ginger, *colocasia*, onion, garlic, coriander, beans, cucurbits, brinjal, lady's finger, maize, mustard leaf, spinach, chilli, tomato, radish and fenugreek were grown during the year on a subsistence basis.

1000 to 1500 m asl

Mangoli Joylikot and Ramgrah villages of Nainital district were selected to conduct the study. The average annual rainfall at this altitude was around 1980 mm. The minimum temperature of study sites was 8.5^{0}C (January) to 23.0^{0}C (June) and maximum between 23.0^{0}C (January) and 36.0^{0}C (June) **(Table 1).**

A total number of 23.7±2.3 households were recorded during the study period. The average population of the study site was 125.3±18.5 of which 44.3±6.5 were adult male, 39.7±6.6 adult female and 41.3±12.1 children. The livestock population in the villages at the time of study was recorded to be 79.7±31.6 with 28.3±10.6 cows, 8.0±6.9 buffaloes, 16.7±11.0 bullocks, 7.7±8.0 goat, 1.3±2.3 hens and 17.7±5.7 calves **(Table 3).**

The average cultivated land holding in each village was 16.7±5.9 ha, of which 4.1±1, 0.33±0.3 and 1.4±0.6 ha was respectively, under agrisilvicultural,

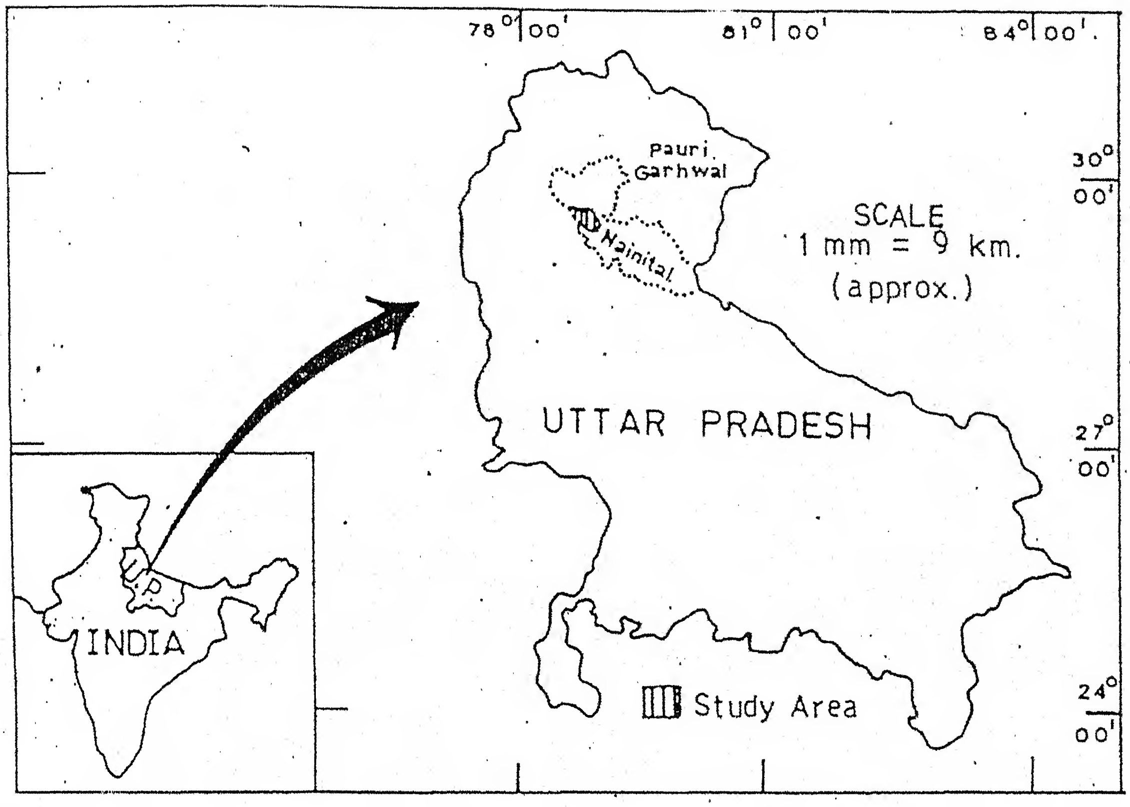
agrihorticultural and agrihortisilvicultural practices with only 4.6±3.7% irrigated land. Farmyard manure was the main source of fertilizer at this altitude. Fodder was mainly obtained from traditional agroforestry systems, whereas *Quercus leucotrichophora* was the main fodder yielding tree species. Other fodder and fruit yielding tree species in the agroforestry systems include *Bauhinia variegata, Celtis australis, Ficus* spp., *Grewia optiva, Melia azedarach, Morus alba, Ougeinia oojeinensis, Citrus* spp., *Prunus* spp., *Psidium guajava, Musa paradisica* and *Juglans regia*.

neither fodder nor fuel-tree species ?

2000-2500 m asl

Gagar Jalal gaoun and Baggar villages of Nainital district were selected to conduct the study. The rocks exposed belonged to the central crystalline and these were high-grade metamorphic rocks comprising granite, biotic genesis with schists. However, around the study area, mainly granite and genesis were exposed. The average annual rainfall at this altitude was around 2200 to 2700 mm with minimum temperature of 2.5^{0}C (January) to 16.0^{0}C (June), and maximum temperature of 16.0^{0}C (January) to 26.0^{0}C (June) **(Table 1)**. The average total number of 28.7±13.2 households was recorded during the study period with a human population of 177.7±90.0 person, of which 55.3±22.4 were adult male, 54.0±27.5 adult female and 68.3±40.7 children. The livestock population was recorded to be 929.3±459.9 with 75.0±459.9 cows, 14.3±8.3 buffaloes, 317.0±124.1 goat, 416.0±273.6 sheep, 51.0±25.5 bullock, 6.7±5.7 horses, 4.0±5.3 hens, 43.0±28.5 calves, 0.67±1.1 pigeon and 0.67±1.1 rabbit (Table 2.4). The average cultivated land holding was 26.0±13.2 ha, of which 4.7±1.2 ha was under agrihorticultural practices. All the land was rainfed and one/ two crops are taken every year. Inorganic fertilizers were not applied at the entire; however, farmyard manure was applied to the fields twice in a year **(Table 4)**.

Interestingly, the fuel and fodder trees are not cultivated in or around agricultural field and only horticultural species were grown at this altitude. Important horticultural species include *Prunus* spp., *Pyrus* spp. and *Juglans regia*. Fuel and fodder requirement is met out from surrounding forest areas. Vegetable like potato, mustard leaf, pumpkin, bottle gourd and cucumber were grown in agrihorticultural systems.



Map. Location Map of the Study Area

Table 1. Geographical and metrological description of the villages studied across an altitudinal gradient in Kumaun Himalaya.

Altitudinal range (m asl)	Village name	Altitude (m asl)	Latitude (N)	Longitude (E)	Aspect	Temperature (^{0}C)				Annual average rainfall (mm)
						January		June		
						Min (^{0}C)	Max (^{0}C)	Min (^{0}C)	Max (^{0}C)	
380 to 500	Kathgodam	390-430	29^0 22′	70^0 44′	Eastern	10.6	18.5	22.0	38.5	1250-1680
	Ranibagh	410-495	30^0 09′	77^0 37′	Eastern					
	Kotabagh	380-500	30^0 18′	78^0 04′	North-West					
1000 to 1500	Mangoli	1000-1250	30^0 68′	80^0 78′	Eastern	8.5	22.0	20.0	35.0	1840-1950
	Joylikot	1340-1500	29^0 10′	78^0 00′	North-West					
	Ramgrah	1100-1400	30^0 10′	79^0 48′	Southern					
2000 to 2500	Gager	2200-2350	29^0 44′	79^0 23′	Eastern	1.5	10.0	15.0	25.5	2400-3000
	Baggar	2050-2300	28^0 05′	78^0 42′	Western					
	Jalalgoun	2110-2500	30^0 35′	79^0 42′	Eastern					

Table 2. Structure of the villages under investigation at 380 to 500 m asl.

Parameters	Village			Average (± S.D.)
	Kathgodam	Ranibagh	Kotabagh	
Altitudinal range (m asl)	390-430	410-495	380-500	
Total land (ha)	48.26	24.89	33.54	27.2±19.4
Actual cultivated land (ha)	**20.92**	**20.67**	**27.16**	**20.3±14.3**
1- Agri-silviculture AFS land ~~(ha)~~	3.0	0.2	6.3	3.2±2.9
2- Agri-horticulture AFS land ~~(ha)~~	0.92	0.2	-	0.3±0.5
3- Agri-horti-silviculture AFS land ~~(ha)~~	-	-	1.7	0.6±0.8
4- Control agricultural land ~~(ha)~~	26.1	3.5	19.0	16.2±9.4
Cultivated land per household ~~(ha)~~	0.4	0.2	0.5	0.4±0.1
Uncultivated (Fallow) land/ household ~~(ha)~~	1.0	-	0.1	0.6±0.6
Per cent irrigated land in the village	69.9	68.6	7.2	48.6±35.9
Irrigated land per household ~~(ha)~~	0.3	0.2	0.01	0.2±0.1
Per cent rainfed land in the village	30.1	31.4	92.8	51.4±35.8
Rainfed land/ household (ha)	0.1	0.1	0.5	0.2±0.2
Barren area (ha)	7.2	0.9	2.1	3.4±3.4
Average family size people	6.9	9.6	7.0	7.8±1.5
Human density/ha cultivated land	16.8	42.3	14.2	24.4±15.6
Livestock holding/ household	4.0	3.8	6.2	4.7±1.3
Livestock density/ha cultivated land	9.7	16.9	12.7	13.1±3.6
Population with outsides employment (%)	9.8	16.1	7.2	11.0±4.6
Area under bund's of the cultivated land.	0.9	0.1	0.5	0.5±0.4
Total human population	500.0	163.0	384.0	349.0±171.6
Man	130.0	49.0	100.0	93.0±41.4
Woman	126.0	44.0	108.0	92.7±43.1
Child	244.0	70.0	176.0	163.3±88.1
Number of household	73.0	17.0	55.0	48.3±29.0
Total livestock population	292.0	68.0	343.0	233.3±146.6
Cow	14.0	12.0	63.0	29.7±28.9
Buffalo	104.0	15.0	69.0	62.7±45.2
Goat	31.0	6.0	45.0	27.3±20.0
Bullock	64.0	15.0	48.0	42.3±25.4
Horse	6.0	-	5.0	3.7±3.2
Calves	48.0	12.0	73.0	44.3±30.9
Hens	22.0	3.0	5.0	10.0±10.8

What is control?

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Table 3. Structure of the villages under investigation at 1000 to 1500 m asl.

Parameters	Village			Average (± S.D.)
	Mangoli	Joylikot	Ramgrah	
Altitudinal range (m asl)	1000-1250	1340-1500	1100-1400	
Total land (ha)	54.3	26.7	13.5	31.5±20.9
Actual cultivated land (ha)	**18.3**	**21.6**	**10.2**	**16.7±5.9**
1- Agri-silviculture AFS land (ha)	5.0	4.2	3.0	4.1±1.0
2- Agri-horticulture AFS land (ha)	-	1.0	-	0.3±0.3
3- Agri-horti-silviculture AFS land (ha)	1.4	1.6	1.3	1.4±0.6
4- Control agricultural land (ha)	11.9	14.8	5.8	10.8±4.6
Cultivated land per household (ha)	0.9	0.9	0.4	0.7±0.3
Uncultivated (fallow) land/ household (ha)	0.3	0.2	0.04	0.2±0.1
Per cent irrigated land in the village	1.4	-	12.3	4.6±6.7
Irrigated land per household (ha)	0.01	-	0.1	0.02±0.03
Per cent rainfed land in the village	98.6	100.0	87.7	95.4±6.7
Rainfed land/ household (ha)	0.9	0.9	0.4	0.7±0.3
Barren area (ha)	13.9	0.8	2.3	5.6±7.2
Average family size people	5.0	5.4	5.5	5.3±0.3
Human density/ ha cultivated land	5.7	6.3	13.5	8.4±4.4
Livestock holding/household	3.9	1.4	3.6	3.0±1.3
Livestock density/ha cultivated land	4.5	1.7	8.9	5.0±3.6
Population with outsides employment (%)	40.3	21.4	15.9	25.9±12.8
Pasture land (ha)	15.5	-	-	5.1±8.9
Area under bund's of the cultivated land.	0.5	0.7	0.3	0.5±0.2
Total human population	104.0	135.0	137.0	125.3±8.5
Man	38.0	51.0	44.0	44.3±6.5
Woman	34.0	47.0	38.0	39.7±6.7
Child	32.0	37.0	55.0	41.3±12.1
Number of household	21.0	25.0	25.0	23.7±2.3
Total livestock population	82.0	47.0	110.0	79.7± 31.6
Cow	40.0	19.0	26.0	28.3±10.6
Buffalo	4.0	4.0	16.0	8.0±6.9
Goat	-	7.0	16.0	7.7±8.0
Bullock	16.0	6.0	28.0	16.7±11.0
Calves	22.0	11.0	20.0	17.7±5.9
Hens	-	-	4.0	1.3±2.3

Table 4. Structure of the villages under investigation at 2000 to 2500 m asl.

Parameters	Village			Average (±S. D.)
	Gagar	Jalal gaoun	Bagar	
Altitudinal range (m asl)	2050-2400	2100-2300	2001-2500	
Total land (ha)	83.1	32.1	119.0	78.1±43.6
Actual cultivated land (ha)	**30.4**	**11.2**	**36.5**	**26.1±13.2**
1- Agri-horticulture AFS land (ha)	4.3	3.6	5.5	4.8±1.2
2- Control agricultural land (ha)	26.2	7.7	30.0	21.3±12.0
Cultivated land per household (ha)	0.7	0.7	1.4	0.9±0.4
Uncultivated (fallow) land/ household (ha)	-	-	-	-
Per cent irrigated land in the village	-	-	-	-
Irrigated land per household (ha)	-	-	-	-
Per cent rainfed land in the village	100.0	100.0	100.0	100.0±0.0
Rainfed land/ household (ha)	0.7	0.7	1.4	0.9±0.4
Barren area (ha)	52.7	20.9	82.5	52.1±30.8
Average family size people	6.2	5.1	6.9	6.7±0.9
Human density/ha cultivated land	8.8	7.7	4.9	7.1±2.0
Livestock holding/household	23.3	25.7	51.8	33.7±15.8
Livestock density/ha cultivated land	33.0	38.9	37.0	36.3±3.0
Population with outsides employment (%)	4.5	1.7	0.1	2.1±2.2
Area under bunds of the cultivated land.	0.9	0.4	1.2	0.8±0.4
Total human population	267.0	87.0	179.0	177.7±90.0
Man	75.0	31.0	60.0	55.3±22.4
Woman	81.0	26.0	55.0	54.0±27.5
Child	111.0	30.0	64.0	68.3±40.7
Number of household	43.0	17.0	26.0	28.7±13.2
Total livestock population	1003.0	437.0	1348.0	929.3±459.9
Cow	105.0	29.0	91.0	75.0±40.5
Buffalo	17.0	5.0	21.0	14.3±8.3
Goat	371.0	175.0	405.0	317.0±124.1
Sheep	356.0	179.0	716.0	416.0±273.7
Bullock	77.0	26.0	50.0	51.0±25.5
Calves	72.0	15.0	42.0	43.0±28.5
Hens	-	2.0	10.0	4.0±5.3
Pigeon	-	2.0	-	0.7±1.2
Rabbit	-	2.0	-	0.7±1.2
Horse	5.0	2.0	13.0	6.7±5.6

MATERIALS AND METHODS

To study the structure and functioning of traditional agroforestry systems along an elevational gradient, three villages have been selected randomly at each altitude. In all, the area was divided into 3 altitudinal classes (380-500, 1000-1500 and 2000-2500 m asl), hence a total of 9 villages were selected for detailed studies. The sites differed in climatic conditions, land use patterns, socio-economic considerations, agroforestry practices etc., and each represented almost the entire area in which it was located. Further, in each village, 15 random households were surveyed to determine average land holding size, area under different crops, land use, trees and shrubs used for various purposes, and management practices. The information was collected through informal discussion with adult members. Each household was visited at least four times in a year. After a preliminary study, a complete inventory was made at a household level for each village covering more than 60% of the village households, following various methods used described by Mishra and Ramakrishnan (1981, 1982); Maikhuri and Ramakrishnan (1990); Negi (1992); Semwal and Maikhuri (1996); Nautiyal *et al* (1998); Singh *et al* (1997); Negi *et al* (1997); Negi *et al* (1999); Bhatt and Todaria (1990a, 1990b, 1990c); Bhatt and Todaria (1991); Bhatt *et al* (1995); Todaria and Bhatt (1992); Bhatt and Badoni (1995); Bhatt and Chauhan (2003); Nazir *et al.*, 2007; Meghan *et al.*, 2008; Das and Chaturvedi 2008; Agarwal, and Goyal, 2009; and Sood and Mitchell 2009. Data on human population, livestock and other factors were based on enquires involving all households. In general, the information was collected on following parameters:

(i) Cropping patterns,
(ii) Area under different crops,
(iii) Cultivated land under irrigated and rainfed conditions,
(iv) Labour inputs for various agricultural operations,
(v) Quantitative estimation of the fertilizers used during *kharif* and *rabi* crops,
(vi) Firewood and fodder requirements for, etc.

The information's gathered were crosschecked for further confirmation by repeated field visits over a period of two years, i.e. during 2000-2001 and 2001-2002. The area cultivated under irrigated and rainfed condition has been crosschecked with the records of State Revenue Department.

Field Data Investigation

Detailed. questionnaire were prepared to conduct the present study at village level and as well as household level, and the survey was conducted in accordance to following parameters:

Village Survey	
(1) Name of the village	(8) Number of households
(2) Altitude (m asl)	(9) Population: (a) Male (b) Female (c) Child (below 12 years of age)
(3) Latitude (E)	(10) Livestock population: (a) Cow (b) Buffalo (c) Bullock (d) Goat (e) Sheep (f) Calf (g) Horse (h) Hens (i) Others
(4) Longitude (N)	(11) Main occupation: (a) Agriculture (b) Service (c) Business (d) Others
(5) Aspect	(12) Land holding (ha): (a) Total land holding (b) Agricultural land (i) Irrigated land (ii) Rainfed land (c) Barren land (d) Pasture land (e) Fallow land (f) Others
(6) District	(13) Cropping pattern: (a) Agricultural crop (i) Winter- Mono or mixed crop (ii) Summer- Mono or mixed crop (iii) Intermediate crop (iv) Cash crops (including vegetable crops); (b) Horticultural tree species, (c) Multipurpose tree species
(7) Distance from road (km)	14. Important agroforestry systems
Source: Negi (1992); Semwal and Maikhuri (1996); Bhatt and Chauhan (2003)	

Your study pertains to 2007 and 2001-02. How this ref. could be used.

Household Survey

(1) Place	(8) Source of fuelwood (including distance travelled): (a) Market purchased (cost/ kg) (b) Collected from forests (I) Private (ii) Government (c) From own plantation/ field (d) Crop residue
(2) Altitude (m asl)	(9) Consumption of fuelwood/kerosene/LPG/cowdung (kg/person/ day): (a) Rainy season (July-September) (b) Winter (October-December) (c) Spring (January-March) (d) Summer (April- June)
(3) Name of the family head and no. of the members in the family: . (i) Male (ii) Female (iii) Child	(10) Species preferred for fuelwood
(4) Persons engaged in fuel and fodder collection: (i) Male (ii) Female (iii) Children	(11) Source of fodder: (a) Market purchased (cost/kg) or (b) Collected from forests, agricultural fields, agroforestry etc., (c) Distance travelled (km)
(5) Time spent (per person/trip/day) for fuel and fodder collection	(12) Fodder consumption (kg/cattle/day) in different seasons: (a) Green fodder (b) Dry fodder
(6) Quantity of fuel (kg/ person/ day) and fodder (kg/animal/ day) collected and consumed	(13) Preferred fodder species
(7) Type of fuel used like: (a) Fuelwood (b) LPG (c) Kerosene (d) Electricity	(14). Use of crop residue
Source: Negi (1992); Swaroop (1993); Bhatt *et al.* (1994); Semwal and Maikhuri (1996); Bhatt and Chauhan (2003)	

Published after ~~your~~ collecting the data.

Agricultural Field Data

Total working hours of oxen/men for per hectare cultivation of land per year for various agricultural works have been estimated. Labour contribution of each family member (male, female and child) was recorded ~~based~~ for various agricultural activities like ploughing, leveling, puddling, hoeing/weeding, irrigation, manuring, ~~fertilizer consumption~~, sowing/transplanting, crop harvesting, tree lopping, fruit picking, threshing, winnowing, transportation of grains and crop by products, etc. Total time spent (hrs) for different activities was ~~were~~ calculated on plot area basis (ranging from 150-200 m^2 for each plot). The total labour consumed was than categorized as sedentary, moderate or heavy work so as to calculate the energetic efficiencies of different systems along an altitudinal gradient.

Growth and Productivity of Tree species

The details of the observational procedure related to different parameters studied have been shown below:.

Tree density

For tree density determination, 20 quadrats of 10 m x 10 m size were laid in all the agroforestry systems following the methodology outlined by Trivedi *et al* (1987) and Toky *et al* (1989a), and the tree density from the respective quadrats was calculated as:

$$\text{Density (D)} = \frac{\text{Total number of individuals of the species}}{\text{Total number of quadrats studied}}$$

Tree height

Total height of various tree species was measured following shadow and single pole method. Further, bole height and crown height of each species was measured separately following the methodology given by Chaturvedi and Khanna (2000). Bole height was recorded from the ground level to the first branches of a tree. For each species, bole and crown height was measured in 10 randomly selected trees in each agroforestry system (AFS).

Tree diameter

Diameter was measured at 1.37 m above the ground level in all the selected agroforestry trees with the help of vernier caliper. For each species, tree diameter was measured in 10 randomly selected trees in each agroforestry system (AFS).

Timber volume

Volume of the timber yielding species having been recorded using the quarter girth formula as mentioned below (Chaturvedi and Khanna, 2000):

Volume of log = $(g/4)^2 \times l$

Where, g = girth of log at the middle, and l = length of the log

Biomass Productivity of Agroforestry Trees

Branch and leaf biomass was recorded following the procedure of Toky *et al.* (1989a); Atul *et al* (1994) and Nautiyal *et al* (1998). Biomass of current twigs was estimated by harvest method (Punam, 1989). In fodder trees, current twigs were divided into five diameter classes at one cm interval from 0 to 5 cm. Ten twigs of each diameter class for a species were clipped and fresh weight of leaves and wood separately was recorded. On an average, 10 trees of each species were used for calculation of current twig biomass. Dry weight was calculated on the basis of the weight of samples dried at 80±4^{0}C. Average tree density of each species, on the basis of vegetation description, was used to calculate the twig productivity.

Fruit yield

The fruit yield was recorded during winter and summer season by weighing the total no of fruits on a plant at the time of harvest and expressed in kg/ plant. For each species, fruit productivity was recorded for 10 trees at each altitude (Toky *et al.*, 1989a; Semwal and Maikhuri, 1996). yield cf

yield

Crop ~~Productivity~~ crop biomass

Grain yield and crop byproductyield was estimated using the quadrat method as followed by earlier workers for different agro-ecosystems of western Himalayas (Ralhan *et al.*, 1992; Singh and Singh, 1987; Sharma, 1991; Toky *et al.*, 1989a; Negi, 1994). On an average, for each crop, 20 quadrats (1 x 1 m) were randomly placed in the standing crop fields and the total above ground biomass

accommodated in the quadrat was harvested. Grains, husk and straw were separated for each quadrat and the productivity was recorded on dry weight basis. Below ground biomass was not estimated in different AFS as it was not possible to estimate the below ground production of tree species in traditional AFS. Hence to keep the homogeneity in the results along an elevational transact, below ground productivity of agricultural crops has also been not mentioned.

yield

biomass

yield

Fodder Productivity from the Weeds and Grasses

Bund area in each agroforestry system was measured. The fodder production from the bunds of the agricultural fields was estimated by the harvest method using 20 (1 x 1 m) quadrats randomly located at the time when the above ground biomass was at its maximum following the monsoon. The grass yield was expressed in kg/ha on green (fresh) weight basis (Punam, 1989; Atul *et al.*, 1994; Negi, 1992; Semwal and Maikhuri, 1996).

expresses on dry weight basis. Follow standard units

Fodder and Fuelwood Consumption

The quantity of fuelwood and fodder consumption was measured over a period of 24-h using a weight survey method (Bhatt *et al.*, 1994; Arrora and Porwal, 2002; Reynolds and Nautiyal, 1987; Agrawal and Joshi, 1993; Hall *et al.*, 1982; Reddy, 1981; Donovan, 1981; Wijesinghe, 1984; Hegde, 1984; Mahat *et al.*, 1987). The wood and fodder were weighed using 50-kg spring balance and then left in the respective house. Each household was requested to burn the wood or use the fodder (fresh and dry) only from the weighed bundle. After 24 h, the actual consumption was measured. Time spent for fuelwood and fodder collection was also recorded. The distance travelled and the time spent for fuelwood and fodder collection was crosschecked by visiting the area with the villagers during the period of collection. Based on Gopalan *et al.* (1978), the time and labour spent for fuel and fodder collection by the household members was measured in hrs and then converted into energy (MJ). Total fuel and fodder energy consumed was apportioned to each activity (Leach, 1976) according to relative duration on the basis of sedentary, moderate or heavy work.

Phyto-sociological Study for Tree Species

Vegetation stratification of different tree species in isolation and in integration with each other was observed in different fields and then all the fields were numbered to facilitate data collection (Punam, 1989). Every individual field was selected indicating the position of crops, weeds and horticulture as well as silviculture trees. The structure of the system was studied by the quadrat method (Mishra, 1968). Since the assemblage of plant community was largely heterogeneous, determination of the quadrat size and number was a prerequisite for proper sampling. The quadrat size was determined with the help of species area curve method (Mishra, 1968) and it worked out to 10 m x 10 m. Though the quadrat number ranged between 15 to 20 for different species growing in the system, the sample size was kept at 20 for all the components of the system under study. forest

The importance value index (IVI) which is an integrated measure of the relative frequency, relative density and relative basal area was calculated for each species as per the methodology suggested by Curtis (1959). All the farmers' fields specifically agroforestry fields were divided on structural basis, in three types of systems. These three systems were having the combination of forest ~~silviculture~~- agriculture, horticulture- agriculture and forest ~~silvicult~~ure-horticulture-agriculture components. Silvipastoral component was also taken into account. For ecological classification of agroforestry systems, Importance Value Index (IVI) exercise was undertaken:

The required number of quadrats (20) in each case was selected at random with the help of random number table (Zar, 1974) and followed throughout the study. For quantifying the importance of the species in a system, the relative frequency, relative density and relative dominance were studied in totality with the help of index values. Misra (1968) and Trivedi *et al.* (1987) have profounded the following formula to work out the IVI values. Propounded

Relative Dominance (R. Dom.)

$$\text{Relative Dominance} = \frac{\text{Total basal area of the species in all the quadrates}}{\text{Total basal area of all the species in all the quadrates}} \times 100$$

Basal area refers to the ground actually penetrated by the stems. It is one of the chief characters determining dominance and the nature of the community. For determining the basal area by metallic tape, the following formula was applied (Mishra, 1968):

Basal area of a species $= \pi r^2$,

$$\text{Where r (radius)} = \frac{\text{Average diameter}}{2}$$

$$\text{Basal area} = \frac{\pi \times (\text{diameter})^2}{4}, \text{ or}$$

Basal area = 3.14 x (diameter)^2 x 0.25

Total basal area (TB) = Basal area/individual x tree density/ha

Frequency, relative frequency and relative density of agroforestry trees spp. was calculated as follows:

$$\text{Frequency (F)} = \frac{\text{Total number of quadrats in which a species occurred}}{\text{Total number of quadrats sampled}}$$

$$\text{Relative Frequency} = \frac{\text{Number of occurrence of a species}}{\text{Number of occurrence of all the species}} \times 100$$

$$\text{Relative Density} = \frac{\text{Number of individuals of a species}}{\text{Number of individuals of all the species}} \times 100$$

ce

Important Value Index (IVI)

Importance Vale Index = R. F. + R. D. + R. Dom.

2 2

The IVI values, thus obtained, will help in quantifying the importance of a particular species in the system or in other words will help in the sequential classification of various structural units of the system in predominance order.

Cropping Schedule

Sequential sowing and harvesting of important crops (cereals and millets, pulses and oilseeds) along an altitudinal gradient has been depicted in **Table 5.** For important vegetables and spices, sowing and harvesting scheduled has been given in **Table 5.1. Table 5.2** represents the details of harvesting scheduled of fuel and fodder, and fruit trees at different altitudes.

Estimation of Various Inputs to Agricultural Operations

Seed, farmyard manure/fertilizer input

During the cropping seasons at household level, the plot area (where the agricultural operations were to be conducted) was measured. The cereal/ grain brought by the farmer for sowing were weighed using top pan balance (500 g capacity) and it was handed over to the farmer for sowing. The left over was again weighed to estimate the actual quantity used for sowing on plot area basis. In all, the inputs were measured in 10 randomly selected plots. The average plot area varied from 50-100 m^2 depending on the crop or crop ~~compositions~~ mixture to be sown. Similarly, the bullock labour and human labour (separately for male, female, and child- in hrs) was computed. The FYM consumption was also recorded on plot area basis in 10 randomly selected plots for each crop. The same plots were surveyed frequently to know the different operations and time (hrs) was recorded till the final harvesting including transportation/ storage of the respective crop (Punam, 1989; Ralhan *et al.*, 1992; Sundriyal *et al.*, 1994; Maikhuri *et al.*, 1996; Singh *et al.*, 1997; Pandey and Singh, 1984; Rai, 1993).

Energy inputs

The input of human and bullock labour, seed/planting material, farmyard manure/fertilizer estimated was converted into energy values as per the standards given by Mitchell (1979); Gopalan *et al* (1978) and Leach (1976). The average input in terms of fertilizers and compost were based on the calorific

values as given by Mitchell (1979). The calorific value of compost was of the organic material. This did not include the energy needed to collect it. The human labour and bullock inputs consisted of food energy values required to meet maintenance costs and those of the labour devoted to collection and agricultural activities, such as ploughing, leveling, puddling, hoeing, manuring, irrigation, stacking, sowing, weeding, harvesting, fruit picking, tree lopping, threshing and winnowing, and carrying/ transportation. Duration of sedentary, moderate and heavy works by males and females in various activities (Leach, 1976) and bullock power use were noted. The input of energy through seed was calculated on the basis of the total energy expended to produce that fraction of the crop yield (Mitchell, 1979; Gopalan *et al.*, 1978). Energetic values used for calculating the energy input in various systems has been shown in **Table 6.**

Energy inputs (Mj/hr/ha) = Working time (hr/ha) X Energy content (Mj/hr)

Energy outputs

The energy output in terms of grain, pulses, oilseeds, vegetables, dry fodder (straw and hay), and green fodder from bunds, weed, tree leaves and fruits obtained from the agricultural fields was converted into calorific values as given by Mitchell (1979), Pimental *et al* (1973) and Gopalan *et al* (1978). Energetic values used for calculating the energy outputs in various systems have also been shown in **Table 6.**.

Energy output (Mj/kg/ha) = Productivity (kg/ha) X Energy contents (Mj/kg)

Monitory input and output

Estimation of monitory input and outputs for each system has been recorded at each altitudinal gradient. The monitory input (Rs/ha) includes the cost of seed, fertilizer, human labour (male, female and child labour) required for ploughing, leveling, puddling, hoeing/ weeding, manuring, irrigation, sowing/ transplanting, bunding, staking, lopping of trees for fuel and fodder, fruit picking, crop harvesting, threshing & winnowing, and carrying/ transportation. The total human labour was estimated in hrs and the one man-day was calculated as eight hrs duty per day. Accordingly, total man-days of male, female and child labour were

computed and rates for each man-day was fixed on prevailing market rate assuming that if the person would not have been engaged in agricultural operations, he would have earned the wages from other source viz. doing the labour work in the nearby towns. The total input was than expressed in Rs/ha. Similarly, for bullock labour, the rates mentioned in the present thesis has been fixed as per the prevailing hiring charges of the bullock pair employed for agricultural operations by the farming families who do not rear bullock themselves. The cost of farmyard manure has also been mentioned based on the purchase cost of FYM in that particular village. Accordingly, the rates of the fodder, fuel, fibre etc have been estimated.

Similarly, for monitory output, the cost of cereals/ grain, and crop byproduct including fodder and fruit yield has been fixed based on the prevailing market rates or values of various outputs were calculated on the basis of buying and selling price in village during the year 2001 to 2002, the period of study. Prevailing market rates (Rs/kg) of different crops along an altitudinal gradient have been shown in **Table 7**. Similarly the buying/ selling prices of different fruit species have been shown in **Table 7.1.** Buying and selling price of tree fodders has been given in **Table 7.2**, whereas **Table 7.3** depicts the cost of fibre obtained from *Grewia optiva*, cost of fodder obtained from weeds/ grasses, cost of firewood, straw, FYM, bullock and human labour. The net monitory benefits have been calculated as total monitory output - total monitory input, and expressed in Rs/ha. The similar methodology has been adopted by various workers for monetary evaluation of the agro-ecosystems of Central Himalaya, India (Nautiyal *et al.*, 1998; Singh *et al.*, 1997; Maikhuri *et al.*, 1996; 1997b,c; Rana, 1995; Rana *et al.*, 1996; Pathak and Singh, 2000; Tiwari, 1982).

Superfluous. It is not required. Procedure adopted is a standard mathematical fundamentals. It doesn't need any support.

Table 5. Sequential sowing (S) and harvesting (H) of some important crops along an altitudinal gradient.

Crops	English name	Local name	380 to 500 m asl		1000 to 1500 m asl		200 to 2500 m asl	
			S	H	S	H	S	H
Cereals & Millets								
Amaranthus spp.	Amaranth	Chaulai	-	-	May- June	Sep- Oct	May	Oct
Echinochloa frumentosea	Barnyard millet	Jhangora	May-June	Sept.	March- April	Aug- Sep	-	-
Eleusine coracana	Finger millet	Koda	-do-	-do-	May	Sep	April	Sep
Hordeum himalayens	Nacked barley	Wajau	-	-	-	-	-	-
H. vulgare	Barley	Jau	Nov- Dec	April	Oct- Nov	May	Oct	June
Oryza sativa	Paddy	Dhan	July	Oct-Nov.	May- June	Nov	-	-
Panicum miliaceum	Hog millet	Cheena	April	June	-	-	-	-
Fagopyrum esculentum	Buckwheat	Ogal	-	-	-	-	July	Oct
Fagopyrum tataricum	Buckwheat	Kettu/ phapar	-	-	-	-	July	Oct
Setaria italica	Foxtail millet	Kauni	-	-	-	-	-	-
Triticum aestivum	Wheat	Gehun	Nov-Dec	April	Oct- Nov	May	Oct	June
Zea mays	Maize	Makai	June	Sep	June	Oct	April	Oct

Pulses								
Cajanus cajan	Pigeon pea	Tor	Feb-March	Oct	March	Nov	-	-
Glycine max	Soybean	Soyabean	May-June	Sep	May- June	Sep- Oct	-	-
G. soja	Soybean	Bhatt	-do-	-do-	-do-	-do-	-	-
Lens esculentus	Lentil	Masoor	Nov	March	Oct- Nov	April	-	-
Macrotyloma uniflorum	Horse gram	Gahat	-do-	-do-	May- June	Sep- Oct	-	-
Phaseolus vulgaris	Kidney bean	Razama	Octo	April	April	Sep- Octo	April	Oct
Pisum sativum	Pea	Matar	Nov	March	Oct- Nov	April	-	-
Vigna mungo	Black gram	Urd	-	-	May- June	Sep- Oct	-	-
V. radiata	Green gram	Mung	April	June-July	-	-	-	-
V. unguiculata	Cow pea	Sonta/ Lobia	May-June	Sep	Sep- Oct	May- June	-	-
Oil seeds								
Brassica compestris	Mustard	Lai	Oct-Nov	March	Oct- Nov	April	-	-
Brassica sp.	Mustard	Toria	-	-	-	-	June- July	Oct
Sesamum indicum	Sesame	Til	June	Oct	-	-	-	-

Table 5.1. Sequential sowing (S) and harvesting (H) of important vegetables and spices crops along an altitudinal gradient.

Vegetables	English name	380 to 500 m asl		1000 to 1500 m asl		2000 to 2500 m asl	
		S	H	S	H	S	H
Zingiber officinale	Ginger	Dec	Oct	-	-	-	-
Colocasia esculenta	Elephant ear	-do-	-do-	Dec	Jan	-	-
Curcuma domestica	Turmeric	-do-	-do-	-	-	-	-
Solanum tubrosum	Potato	Oct	Jan-Feb	Oct- Nov	Feb	April	Sep- Oct
Allium cepa	Onion	Nov	June	Nov	July	-	-
A. sativum	Garlic	-do-	-do-	-	-	-	-
Capiscum frutescens	Chilli	April	Oct	May	Nov	-	-
Hibiscus esculentus	Ladies finger	-do-	-do-	-do-	-do-	-	-
Lycopersicum esculentum	Tomato	-do-	-do-	-do-	-do-	-	-
Solanum melongena	Brinjal	-do-	-do-	-do-	-do-	-	-
Legenaria leucontha	Bottle gourd	-do-	-do-	-do-	-do-	April	Nov
Cucurbita pepo	Pumpkin	-do-	-do-	-do-	-do-	-do-	-do-
Cucumis sativum	Cucumber	-do-	-do-	-do-	-do-	-do-	-do-
Momordica charentia	Bitter gourd	-do-	-do-	-do-	-do-	-	-
Trichosanthes anguina	Snake gourd	-do-	-do-	-do-	-do-	-	-
Coriander sativum	Coriander	Oct- Nov	Feb- March	-	-	-	-
Brassica juncea	Mustard leaf	Oct	Dec-Jan	Oct-Nov	Jan	April	June- July
Spinacia oleracea	Spinach	Nov	Feb	-	-	-	-
Trigonella foenumgraecum	Fenugreek	-do-	-do-	-	-	-	-
Raphanus sativus	Radish	-do-	-do-	April- May	Aug	-	-
Phaseolus vulgaris	French bean	April	July	April- May	July- Aug	-	-
Brassica oleracia	Cabbage	Oct	Feb	-	-	-	-

Table 5.2. Harvesting schedule of fodder and fruit trees along an altitudinal gradient in traditional agroforestry systems.

Species	English/ Local name	380 to 500 m asl	1000 to 1500 m asl	2000 to 2500 m asl
Fodder trees				
Albizia lebbek	Siris	May June	-	-
Bauhinia variegata	Guiral	March-April	Jan-March	-
Boehmeria rugulosa	Genthi	Nov-Jan	-	-
Celtis australis	Kharik	-	April-June	-
Ficus auriculata	Timla	April-May	Dec-Feb	-
F. hispida	Ghogsu	Nov-Jan	-	-
F. cunia	Khainda	Nov-Jan	Dec-Feb	-
F. palmata	Bedu	April- May	-	-
Grewia optiva	Bhimal	Jan-March	Dec-March	-
Leucaena leucocephala	Subabul	-do-	-	-
Mallotus phillippensis	Ruhida	March- May	-	-
Melia azedarach	Dainken	March-June	April- June	-
Morus alba	Sahtoot	Feb-March	May-July	-
Morus serreta	Kemu	-	May-July	-
Ougeinia oojeinensis	Sanen	April- May	May- June	-
Quercus leucotrichophora	Oak/ Banj	-	Nov-March	-
Fruit trees				
Artocarpus heterophyllus	Kathal	May- June	-	-
Carica papaya	Papita	April- June	-	-
Citrus aurantifolia	Kagji Lime	-	-	
C. maxima	Chakotra	-	-	-
C. limonia	Bara nimbu	-	Nov-Dec	-
C. reticulata	Santra	Sep-Oct	Nov-Dec	-
C. sinensis	Malta	-	Sep-Nov	-

Litchi chinensis	Litchi	May-June	-	-
Mangifera indica	Aam	May-June	-	-
Prunus persica	Peach/Aaru	May-June	July	Sep
Prunus armeniaca	Khubani	-	-	June
Prunus domestica	Plum	-	-	June-July
Psidium guajava	Guava	Oct-Nov.	Dec-Jan.	-
Musa paradisiaca	Banana	-	-	
-Pyrus malus	Apple	-	-	-
Pyrus communis	Pear	-	-	-
Juglans regia	Akhrot	-	-	Sept

Table 6. Energetic values of different outputs and inputs in different agroforestry systems of Himalaya.

Category	Energy Value	Category	Energy V-alue
Grains	16.2 Mj/kg	Tubers (Potato)	3.9 Mj/kg (15.3 Mj/kg)
Pulses	17.0 Mj/kg	Leafy vegetables	2.8 Mj/kg (15.0 Mj/kg)
Oil seeds	23.07 Mj/kg	Hay	14.5 Mj/kg
Other vegetables	2.4 Mj/kg (13.8 Mj/kg)	Straw	13.9 Mj/kg
Rhizome (Ginger and Turmeric)	2.8 Mj/kg (15.3 Mj/kg)	Fruits	14.92 Mj/kg
Green fodder	3.9 Mj/kg (15.8 Mj/kg)	Fuelwood	19.7 Mj/kg
Tree and Shrub leaves	4.2 Mj/kg (16.8 Mj/kg)	Farmyard manure	7.3 Mj/kg
Human labour-Male		Fertilizer	30.3 Mj/kg
Sedentary work	0.4 Mj/h**	Diesel	46.7 Mj/Ltr
Moderate work	0.5 Mj/h**	Sesame	26.6 Mj/kg*
Heavy work	0.7 Mj/h**	One bullock-day	72.7 Mj/day*
Human labour-Female		Cow dung	4.1 Mj/kg
Sedentary work	0.3 Mj/h**	Kerosene	9.8 Mj/Ltr
Moderate work	0.4 Mj/h**	LPG	10.8 Mj/Ltr
Heavy work	0.5 Mj/h**	Source: Mitchell (1979); *Gopalan *et al.* (1978); **Leach (1976). Figure in parenthesis represents the energy values on dry weight basis	
Adult children (9-12 years) for heavy work	0.4 Mj/h**		

Table 7. Prevailing market rates (Rs/kg) of different crops along an altitudinal gradient.

Crops	Altitudinal range (m asl)				
	380- 500	500-1000	1000-1500	1500-2000	2000-2500
Wheat	6.0 (8.0)	7.0 (8.0)	8.0	8.0	8.0
Barley	4.0 (5.0)	6.0	6.0	6.0	6.0
Finger millet	5.0	5.0	5.0	5.0	5.0
Barnyard millet	5.0	5.0	5.0	5.0	5.0
Hog millet	5.0	5.0	-	-	-
Foxtail millet	-	-	-	7.0 (8.0)	-
Paddy	5.0 (6.0)	5.0 (6.0)	6.0	7.0	5.0
Buck Wheat	-	-	-	-	14.0 (16.0)
Nacked barley	-	-	-	8.0	-
Maize	8.0	8.0	8.0	8.0	8.0
Pea	14.0	14.0	14.0	18.0	-
Amaranth	-	20.0 (30.0)	20.0 (30.0)	20.0 (30.0)	20.0 (30.0)
Lentil	20.0	20.0	20.0	20.0	-
Horse gram	-	16.0	16.0	16.0	-
Pigeon pea	20.0	20.0	22.0	22.0	-
Black gram	20.0	18.0 (20.0)	20.0	20.0	-
Cow pea	13.0	13.0	10.0 (12.0)	10.0	-
Soyabean	14.0	15.0	15.0	15.0	-
Rajmash	20.0 (22.0)	20.0 (24.0)	22.0	24.0	24.0
Green gram	20.0 (22.0)	-	-	-	-
Mustard	10.0 (12.0)	12.0	12.0	12.0	-
Mustard (Var. Toria)	-	-	-	-	14.0
Sesame	20.0	22.0	-	-	-
Potato	3.0 (5.0)	4.0 (6.0)	5.0	5.0 (4.0)	5.0 (4.0)
Onion	4.0 (160.0)	5.0 (160.0)	6.0 (160.0)	-	-
Garlic	10.0	(10.0) 12.0	-	-	-
Turmeric	7.0 (8.0)	7.0 (8.0)	-	-	-
Ginger	10.0 (15.0)	10.0 (15.0)	-	-	-
Elephant ear	2.0 (3.0)	3.0 (4.0)	4.0	4.0	-
Coriander	20.0 (25.0)	20.0 (22.0)	22.0	22.0	-
Fenugreek	20.0 (25.0)	23.0 (25.0)	-	-	-
Pumpkin	3.0 (80.0)	4.0 (80.0)	4.0 (80.0)	4.0 (80.0)	4.0 (80.0)
Bottle gourd	3.0 (80.0)	4.0 (80.0)	4.0 (80.0)	4.0 (80.0)	4.0 (80.0)
Snake gourd	5.0 (80.0)	6.0 (80.0)	-	-	-
Bitter gourd	5.0 (70.0)	6.0 (70.0)	-	-	-
Ladies finger	4.0 (45.0)	6.0 (45.0)	6.0 (50.0)	-	-
Chilli	15.0 (150.0)	16.0 (170.0)	16.0 (170.0)	17.0 (170.0)	17.0 (170.0)
Tomato	5.0 (370.0)	6.0 (370.0)	6.0 (370.0)	6.0 (370.0)	-
Brinjal	3.0 (350.0)	5.0 (350.0)	5.0 (350.0)	5.0 (350.0)	-
Franch bean	4.0 (25.0)	5.0 (25.0)	5.0 (25.0)	5.0 (25.0)	5.0 (25.0)
Cabbage	3.0 (320.0)	4.0 (350.0)	-	-	-
Mustard leaf	2.0 (15.0)	3.0 (18.0)	2.0 (18.0)	3.0 (18.0)	3.0 (18.0)
Spinach	2.0 (80.0)	4.0 (80.0)	-	-	-
Radish	2.0 (20.0)	4.0 (20.0)	4.0 (20.0)	4.0 (20.0)	-
Cucumber	4.0 (100.0)	5.0 (100.0)	5.0 (100.0)	5.0 (120.0)	5.0 (120.0)

Figure in parenthesis represents the market rates of seeds used for sowing

Table 7.1. Prevailing market rates (Rs/kg) of different fruits along an altitudinal gradient.

Crops	Altitudinal range (m asl)				
	380 to 500	500-1000	1000-1500	1500-2000	2000-2500
Mangifera indica	10.0	10.0	10.0	-	-
Litchi chinensis	15.0	20.0	-	-	-
Carica papaya	10.0	10.0	10.0	-	-
Psidium guajava	5.0	6.0	6.0	-	-
Musa paradisica	7.0	10.0	-	-	-
Citrus aurantifolia	10.0	10.0	-	-	-
C. reticulata	10.0	10.0	6.0	8.0	-
C. maxima	7.0	5.0	6.0	5.0	-
C. limonia	7.0	5.0	5.0	5.0	-
C. sinensis	12.0	10.0	6.0	5.0	-
Prunus persica	5.0	6.0	5.0	5.0	4.0
P. armeniaca	-	5.0	5.0	7.0	5.0
P. domestica	-	-	-	5.0	5.0
Juglans regia	-	-	20.0	20.0	15.0
Pyrus communis	-	-	5.0	5.0	4.0
Pyrus malus	-	-	8.0	8.0	7.0
Artocarpus heterophyllus	7.0	10.0	-	-	-

Table 7.2. Prevailing market rates (Rs/kg) of different fodder tree species.

Tree species	Rates	Tree species	Rates
Albizia lebbek	2.0	*Grewia optiva*	3.0
Bauhinia variegata	3.0	*Leucaena leucocephala*	3.0
Boehmeria rugulosa	3.0	*Mallotus phillippensis*	2.0
Celtis australis	3.0	*Melia azedarach*	2.0
Ficus auriculata	3.0	*Moringa pterygosperma*	2.5
F. hispida	3.0	*Morus alba*	3.0
F. cunia	3.0	*M. serreta*	3.0
F. palmata	3.0	*Ougeinia oojeinensis*	2.5
Quercus leucotrichophora	2.5		

Table 7.3. Prevailing market rates (Rs/kg) of some other items.

Items	Rate	Items	Rate
Fodder from weed & grasses	1.0	*Grewia optiva* fibre	35.0
Fuelwood	1.0	FYM	0.50
Straw	0.5	Urea	4.5
One man/day	70.0	DAP	8.5
One woman/day	50.0	Bullock labour (One pair/day)	150.0
One child/day	30.0		

REVIEW OF LITERATURE

Over the years, farmers have been integrated tree + crop + animal components for sustenance. With the passage of time, the agricultural component received priority over woody elements for sustaining self-sufficiency in food grains. The population pressure resulted in small holdings and consequently lesser number of trees on the farms providing food, fodder, fibre, fuel, fertilizer, fruit, etc. The introduction of high yielding crops has no doubt resulted in self sufficiency in food grains but its role in degrading topsoil by increasing solini due to faulty irrigation, loss of fertility and deposition of non-biodegradable agricultural chemicals in soil cannot be overlooked.Agroforestry represents an approach of integrated land use that involves deliberate retention or admixture of trees and other woody perennials in crop/animal production fields to benefit from the resultant ecological and economical interactions (Raintree, 1984; Nair, 1985 a, b). Agroforestry has received much attention in India from researchers, policymakers and others for its perceived ability to contribute significantly to economic growth, poverty alleviation and environmental quality, so that today agroforestry is an important part of the 'evergreen revolution' movement in the country (Puri and Nair, 2004). National Agriculture Policy 2000 of India underlined the need for diversification in agriculture with the promotion of integrated development of rainfed areas on watershed basis and augmentation of biomass production through agroforestry with demand-driven community participation (Samra and Solanki, 2004).

Along with the elucidation of the principles and development of the agroforestry concept, various workers (Comb and Budowski, 1979; King, 1979; Grainger, 1980; Vergara, 1981; Nair, 1985 c) have tried to classify it. Most of these attempts formed a part of the exercise in conceptual development rather than an aid in evaluating and analysing existing agroforestry systems. Now the information gathered (ICRAF, 1983) on the structural and functional complexities of the agroforestry system is so extensive that a greater need for classification of such system is experienced. The relevant literature on structure and functioning of traditional agroforestry systems is scanty and also more general in nature. However, for the purpose of present study, available literature has been reviewed as under:

- Identification of important agroforestry systems and promising tree species,
- The agroecosystems,
- Land use patterns,
- Contribution of agroforestry trees in terms of fuel, fodder and timber,
- Cropping patterns, and
- Cropping and yield patterns in terms of energy & monetary benefits.

Identification of Important Agroforestry Systems and Promising Tree Species

Several reports describing the major agroforestry systems in the country are available (Nair, 1989; Tejwani, 1993, 1994, 1987; Kumar, 1999; Pathak and Solanki, 2002). Various location specific agroforestry practices have been described by these workers. Hilly regions in India show the agricultural evolution from forests in the form of agroforestry systems, which are location specific, tribe specific and conservation based (Peter and Holzer, 1998; Singh *et al.*, 1989; Sundriyal *et al.*, 1994; Singh, 1998). Important agroforestry systems of Central Himalaya has also been described by many workers (Todaria, and Bhatt, 1992; Nautiyal and Purohit, 1988; Nautiyal *et al.*, 1998; Negi and Singh, 1990; Swarup, 1993; Semwal and Maikhuri, 1996; Toky *et al.*, 1989a, b; Pathania and Uppal, 2000; Bhatt and Badoni, 1995; Gaur, 1999; Ghildiyal, 1991; Gupta, 1986, 1993; Khosla *et al.*, 1992; Maikhuri *et al.*, 1997b,c; Negi, 1995; Negi *et al.*, 1979; Bhatt, 2003; Nazir *et al.*, 2007; Singh and Sharma, 2007; Saha *et al.*, 2007; Bellow *et al.*, 2008; Meghan *et al.*, 2008; Houx, *et al.*, 2008; Das and Chaturvedi 2008; McGraw, *et al.*, 2008; Schoeneberger, 2009; Agarwal, and Goyal, 2009; Sood and Mitchell 2009).

Although many traditional multipurpose trees have been recognized as valuable, efforts in selection and improvement of such species have been generally lacking (Kedharnath, 1984 and1986; Puri and Nair, 2004). Toky *et al* (1992) listed more than 250 indigenous multipurpose trees present in different eco-region of India, including many lasser known species that need domestication. Species like *Albizia lebbek*, *A. procera*, *A. chinensis*, *Azadirachta indica*, *Casuarina equisetifolia*, *Dalbergia sissoo*, *Dendrocalamus spp.*, *Melocanna baccifera*, *Gmelina arborea*, *Prosopis juliflora*, *Leucaena leucocephala*, *Calliandra calothyrsus*, *Grewia optiva*, *Celtis australis*, *Ficus* spp., *Bauhinia* spp.,

Boehmeria rugulosa, Ougeinia dalbergioides, Terminalia spp., *Alnus nepalensis, Michelia* spp., *Exbucklandia populnea, Desmodium elegans* etc. are in a process of domestication and/or commercialization (Naugraiya and Puri, 2001; Tewari, 2001; Bhatt, 1991; Butola, 2004; Chauhan, 1998; Nautiyal and Purohit, 1988; Chauhan *et al.*, 2000; Gairola *et al.*, 1990; Rana, 1988; Negi *et al.*, 1992; Pathak, 2002, Nazir *et al.*, 2007; Banful, *et al.*, 2007; Bellow *et al.*, 2008; Bayala *et al.*, 2008; Burner and Belesky, 2008; Das and Chaturvedi 2008; McGraw, *et al.*, 2008; Schoeneberger, 2009; Sood and Mitchell 2009).

The diagnosis and designed exercise carried out in earlier two decades has shown the existence of many tree based farming systems and specific choice of multipurpose trees by the farmers. The prominent agroforestry models show wide application of all of them in western Himalayan region while in the eastern region, it is agrihorticultural and hortipastoral systems, which are practiced on a large scale (Dhyani and Tripathi, 1999; Bhatt and Verma, 2002; Bhatt *et al.*, 2001). In general, components of agroforestry varies with altitude, socio-economic set up, availability of resources, food habit, land holdings, soil type, etc (Bhatt, 2003). Over large areas in the western Himalaya, farmers practices the following three types of agroforestry systems and their promising tree species are as:

(i) agri-silvicultural system- *Grewia optiva, Celtis australis, Bauhinia variegeta, Albizia chinensis, A. lebbek, Toona ciliata, Morus serreta, Pistacia integrerrima, Bombax ceiba.*

(ii) agri-horticultural system- *Pyrus malus, Prunus domestica, Citrus* spp., *P. persica, Prunus dulcis, P. amygdalus, P. armeniaca, Pyrus communis, Psidium guajava*

(iii) agri-hortisilvicultural system- species are the same as that in the other two systems (Toky *et al.*, 1989; Atul *et al.*, 1990).

Gaur *et al.* (1993) reported that in western Himalayas, *Grewia optiva, Celtis australis, Ficus palmata, Toona ciliata* and *Melia azedarach* are allowed to grow on the margins of agricultural fields while some species found in the vicinity of the agricultural fields as escapes are *Adina cordifolia, Aegle mormelos, Boehmeria rugulosa, Butea monosperma, Indigofera gerardiana, Pyrus pashia, Erythrina suberosa, Holoptelea integrifolia, Moringa pterygosperma, Kydia calycina, Madhuca indica, Semecarpus anacardium, Sapindus mukurossi, Terminalia alata, Holarrhena antidysenterica* etc. Similar species were identified

in silvicultural agroforestry systems of Kumaun Himalaya (Maikhuri *et al.*, 1997b,c).

Nautiyal and Nautiyal (1988) observed nearly a total of 227 fruits trees, 271 fuel-fodder trees and 200 timber trees existing in traditional agroforestry systems, which shows the tree farming attitudes at individual level of rural folk. Based on Overall Rank Sum Index (ORSI), Nautiyal and Purohit (1988) described important multipurpose tree species for agroforestry systems in Kumaun Himalaya. Accordingly, Bhatt and Verma (2002) listed 40 potential multipurpose trees and shrubs for Northwest and Northeast Himalayas. Mughal *et al* (2000) documented the important agroforestry systems of temperate region of Jammu and Kashmir. Dadhwal *et al.* (1989) have identified agrisilviculture as one of the most dominant agroforestry systems for northwest Himalayas. Similarly, Todaria and Bhatt (1992) reported that agrisilviculture is the dominant system in Kumaun hills of Central Himalaya. Singh and Dagar (1990) described that agrisilviculture, agrihortisilviculture and silvipastoral systems of Mussoorie hills in Western Himalayas. Based on the nature of components, four main classes of agroforestry (namely agrisilviculture, silvopastoral, agrisilvipastoral and aquasilviculture) have been identified for hill regions of India. Keeping in view the arrangement of these components in space and time and their uses, a total of 48 agroforestry system classes has been proposed (Tejwani, 1987). A wide variety of practices in the hill regions of India has been described. The main system classes described were shifting cultivation, taungya, intercropping in horticultural trees, specific agricultural practices associated with forests, trees in agricultural fields and on farm boundaries, commercial crops under shade of trees (e.g. tea, coffee, cardamom etc.), silvopastoral systems and agrisilvipastoral systems (Tejwani, 1987).

According to the structural basis of classification of land use systems, there are three basic sets of elements those are managed by man: the tree (woody perennial), the herb (agricultural crops including pasture species) and animal. A simple classification is given by Nair (1985c) who has classified the agroforestry systems as: agrisilvicultural - crops and trees including shrubs/vines; silvopastoral - pasture/animals and trees, and agrosilvopastoral- crops, pasture/animals and trees. In addition, a few systems such as-

multipurpose woodlots, apiculture with trees and aquasilviculture also fall under the purview of agroforestry definition. Based on the arrangement of components, the species or species mixtures can be in zones or strips of varying widths. A commonly mentioned example of the zonal pattern is the hedgerow inter-cropping (Wilson and Kang, 1981; Ssekabembe, 1985). An extreme form of zonal planting is the boundary planting of trees on edges of plots and fields for a variety of purposes and outputs viz. fruits, fodder, fuelwood, fencing and protection, soil conservation/wind breaks, etc. Home gardens are classified from a land use perspective as an agroforestry system with a mixture of trees, shrubs, herbs and other agricultural crops within household boundary and under the family labour and management (Fernades and Nair, 1986).

Agroforestry is not a new concept particularly in hill agroecosystems as various agroforestry practices are adopted by the rural folk since time immemorial (Nautiyal *et al.*, 1998). It is widely accepted that ecological stability in the farm sector can only be brought about if farmers adopt multi cropping by integrating trees, shrubs, crops and domestic animals (Khurana and Khosla, 1993). Punam (1989) has quantified the agroforestry systems of Himachal Himalayas and brought out a postulate that why a common man/farmer of 21st century should adopt the agroforestry concept. The traditional agroforestry systems are based largely on indigenous knowledge and on species selection, which are part of the cultural patterns of the local community (Khybri *et al.*, 1992). Though a number of studies on Himalayan agroforestry systems are conducted, yet it has also been pointed out by various workers that the data from most of the traditional agroforestry systems is either non existent or of empirical nature (Comb and Budowski, 1979; Nair and Dagar, 1991; Atul *et al*, 1994; Dagar, 1995; Punam *et al.*, 2001). In an extensive review on agroforestry research in India, Puri and Nair (2004) has clearly mentioned that "*a serious problem with most of research efforts in agroforestry is that the research has been limited mostly to technology testing and gathering of observations with very little investigations on the reasons for the observed results. Due to this fact, most of the research results are of limited applicability in situations or locations other than the study sites, and even under different soil and other ecological conditions of the same study region*". Hence the more basic research is yet to be done in agroforestry as it is directly related to sustainability of the farmers.

The Agroecosystems

The recent emergence of the agro-ecosystem concept provides very useful means of carrying out research that attempts to integrate the multiple factors affecting agricultural systems (Spedding, 1975; Loucks, 1977; Hart, 1979; Lambert, 1981; Conway, 1981; Lowrance *et al.*, 1984; Singh and Sharma, 2007; Saha *et al.*, 2007; Escobar,2007; Sharrow, 2007; Banful, *et al.*, 2007; Das and Chaturvedi 2008; McGraw, *et al.*, 2008; Schoeneberger, 2009; Agarwal, and Goyal, 2009;). It is useful to remember that the central concept for such an approach is the ecosystem, defined as a functional system of complentary relations between living organisms and their environment, delimited by arbitrarily chosen boundaries, which in space and time appear to maintain a steady yet dynamic equilibrium (Altieri, 1983).

The diversification of agro-ecosystems with the incorporation of trees is a practice that has a long history. This is especially true in the tropical and subtropical regions of the world where farmers have long planted trees with other agricultural crops and incorporated animals to help provide for the basic needs of food, wood products, fodder and to help conserve and protect their often limited resources (Nair, 1983). In the past decade, particular interest has developed in many variations of this practice and with it, an awareness of the unique productive and protective value of trees in agricultural systems (Felker and Bandurski, 1979; McDaniels and Lieberman, 1979; Getahum *et al.,* 1982; Nair, 1983).

The objective of various agroforestry systems is to optimize the beneficial effects or interactions of the woody components with the crop or animal components to obtain more diversity of products, to lessen the need for out side inputs for the management of the systems, and to lower to environmental impacts of farming practices (Gliessman *et al.,* 1981; Gliessman, 1983). Many of the same techniques used to study multiple cropping systems can be used for the study of agroforestry systems. Thus the agrisilviculture (the management of agro-ecosystems combining agricultural crops and trees) and even silvipastoral systems (animal production systems that incorporate trees) are similar to the inter mixed- cropped types of multiple cropping.

A major step in the study of any complex agro-ecosystem, and especially agroforestry systems, is to determine the patterns of species distribution, dominance and diversity. An understanding of community structure leads to better knowledge about either actual or potential resource use by that system, the dynamics of species interactions as affected by the trees, and the impact of trees on biotic and abiotic factors (Huxley, 1985). Only after gaining an understanding of the organization of the agroecosystem, we can begin to focus on the complex ecological processes that determine both productivity and sustainability. This understanding can then be linked to the intricate social and economic factors that currently have greatest input in determining how an agroecosystem is designed and managed. In agroforestry systems, trees can fill both ecological and cultural roles. Rural communities in tropical countries have integrated forestry and agricultural practices for centuries (F.A.O., 1978). Thus, in the 1970's there was increasing recognition in tropical countries of the role forests and trees can play in increasing agricultural productivity, improving human welfare, alleviating energy problems and conserving the environment (Turnbull, 1984). Moreover, according to F.A.O. (1981), main thrust of forestry in 1990's will be reforestation with fast growing trees with special emphasis on multipurpose trees, around homestead, along boundaries, in village woodlots and in upland watersheds.

Land Use Patterns

The farming systems in Kumaun Hills comprise forest, cropland, livestock and household as the four components in organic linkage with each other (Maikhuri and Rao, 1997). Earlier studies from Central Himalayan of Panday and Singh (1984), Singh *et al.* (1984) and Ralhan *et al.* (1992) indicated that agriculture practice require a massive consumption of forest resources, however, the position at present is that only 24.9% (7453 sq. km) of Kumaun Himalaya is now forested and only 4.1% of the area has a forest with more than 60% crown cover (Singh *et al.*, 1984), which is not sufficient even to maintain the ecological balance in the region. Agriculture of Kumaun hills in closely linked with forestry (Negi *et al.* 1997). Only 3-4 decades ago, the agroecosystems were functioning sustainable due to the availability of ample natural resources, but in recent years, due to over exploitation of forest resources, rapid growth of population,

fragmentation of land holdings, the sustainability of the agroecosystems has been greatly reduced (Semwal and Maikhuri, 1996). On average, 85% of all agricultural land already suffers from severe erosion problems due to the shallowness of the soil and its acute slope (Negi and Singh, 1990). Negi (1992), Negi and Todaria (1993), Negi *et al.* (1997 & 1999), and Bhatt *et al.* (1994) carried out the studies on land use pattern, human impact on forests and energy consumption pattern in Kumaun Himalaya and these studies have shown that more biomass need to be produced to meet out the fuel, fodder, timber requirement of the rural folk and to sustain the agroecosystem of the region. Sundriyal *et al.* (1994) reported that land use systems in the Himalayan region of India comprise forest, agriculture, horticulture, agroforestry and animal husbandry. These components are interdependent and play a vital role in maintainig the economy of the region. Most of the farming system are at the subsistance level (Fonzen and Oberhalzer, 1984; Mishra and Ramakrishnan, 1982; Nair, 1985c; Ralhan *et al.*, 1992; Sharma, 1991; Singh *et al.*, 1989) and have evolved over the years from trial and error by the farmers to meet the demand for food, fodder, fuelwood and timber.

Quantitative information on the tree component and details on the structure and functioning of agricultural systems are lacking (Awasthi and Prasad, 1987; Singh *et al.*, 1989; Subba, 1984), however, tree-crop combinations based on traditional knowledge could become readily acceptable to the local communities (Gilesman *et al.*, 1981; Smith, 1990). Agroforestry can be appropriate rehabilitation treatment in thickly populated mid-altitude areas suffering from crises of all the three essential needs of food, fuelwood and fodder (Maikhuri *et al.*, 1995, 1997 a, b; Gupta, 1979; Ghildiyal, 1980; Gaur, 1984). Planting trees can succeed in situations where scarcity of tree based products (fuelwood, timber and fodder) threaten the livelihood of local communities and/ or where policy provides for monitory benefits from commercial exploitation of timber from planted trees to the local communities (Bartlett, 1992; Fox, 1993). In the past, several workers have taken pain to explore the forest vegetation as well as the ecological analysis of the dominant forest types, but very little was done towards the understanding of agroecosystems. Therefore, what is needed today is the need for better understanding of agroforestry systems of Kumaun Himalaya (Swarup, 1993).

As elsewhere in the central and western Himalaya, agriculture is a highly complex production system where crop husbandry, animal husbandry and forest constitute interlinked systems (Maikhuri *et al.*, 1998; Semwal and Maikhuri, 1996; Palni *et al.*, 1998). They are of particular interest from the ecological point of view in the tropics where land holdings are generally small, loss of nutrients tend to be high due to soil perturbations, and biomass is continuously removed from the system in the form of fodder, fuel, fruits and grains, while the inputs to the systems are minimal (Lundgreen and Nair, 1985). Nair (1985c) has very rightly pointed out that there are some characteristics (both socio-economic and biological) that are common to all such systems, more particularly their subsistence nature. In small holdings, the resources available to the operator, including capital, severely limit opportunities for improvement. Farm size is often small and family labour is usually under-utilized on a year round basis but is inadequate during periods of peak requirements. Small holding land use systems using plantation crop species are characterized by the availability of low cost labour with usually a higher employment turnover, more working days per worker as well as more hours per working day compared to arable cropping. Modern production technologies that are well adopted to the commercial cropping and plantations are of little value to such small farms, mainly because the lack of resources on the part of the farmer which does not allow him to adopt the modern production technologies.

Contribution of Agroforestry Trees in term of Fuel, Fodder and Timber

Agroforestry systems in the tropical and subtropical regions of the world are based primarily on natural occurrence of the trees on a man-managed unit of land and they are also ecological systems modified by human beings to produce food, fuel, fodder and fibre (Vonmaydell, 1984; Nair, 1984; Nye and Greenland, 1960). A change in the recent past from export- oriented agriculture towards agroforestry system based upon local resource utilization in the Himalaya is viewed with increasing interest (Borthakur *et al.*, 1978; Singh, 1987; Swaminathan, 1987). Agroforestry systems offer a significant source of plant material, especially for fuel, fodder and small timber, often contain species that could have great potential on other sites as exotics and hence there is a great

need to conserve this wide variety of germplasm in the tropics (Burley and Voncarlowitz, 1984; Burley, 1987; Khosla, 1985).

Phenological adaptation of the agroforestry trees is also important from the point of view of understanding of the agroecosystem function (Ramakrishnan *et al.*, 1994). Similarly, leaf life span, pattern and leaf fall can be considered a part of strategy of a species to maximize productivity under different environmental conditions (Khosla *et al.,* 1992; Chabot and Hicks, 1982; Horn, 1971). Tree lopping is important for controlling crown spread and increasing light penetration for overall biomass production (Deb-Roy, 1994) and preventing invasion of the land surface by other unwanted species. Traditional agroforestry practices involve the use of trees in various special patterns to meet the wood fuel and fodder requirements of the farmers (Narain *et al.*, 1998).

Various estimates have been made to record the productivity of agroforestry trees in term of fuel and fodder. Deb-Roy (1994) observed more biomass of *Albizia lebbek* at the highest lopping intensity, but Gupta *et al.* (1996) found that reverse was true for *Bauhinia purpurea*. Similarly, Pokhriyal *et al.* (1994) observed more leaf biomass production in *Grewia optiva* at 25% lopping than at 75%. Regrowth in lopped trees was related to a combination of enhanced net assimilation rate, recovery of larger leaf area, delayed leaf senescence and use of current and root- stored carbohydrates for production of new leaf area (Singh and Thompson, 1995). However, the density and looping of the trees are managed such that crown of neighboring trees do not overlap (Chauhan *et al.*, 2001).

Tree density in different agroforestry systems is reported in the range of 182 to 419 per hectare and species richness from 8 to 90 species (Dadhwal *et al.,* 1989; Toky *et al.*, 1989a; Sundriyal *et al.*, 1994; Thapa *et al.*, 1995; Semwal and Maikhuri, 1996; Nautiyal *et al.*, 1998). The mean number of trees per family in the region varies from place to place however, a minimum of 14-16 trees per family have been recorded in Kumaun Himalaya (Negi *et al.,* 1999). Agroforestry contributes to a great extent to meet out the various day to day requirements of the rural folk of Kumaun Himalaya. In a study conducted by Nautiyal *et al.* (1998) in the villages situated between 700 to 1200 m altitude, it has been recorded that (62.8%) of the annual fuelwood requirement was met out by simultaneus and

sequential agroforestry systems. Similarly, 72.4% of the total fodder requirement was fulfilled by the agroforestry systems however, a wide variation in data could be accounted based on the topography, size of land holding, altitude and excessibility of the village in other parts of Kumaun Himalaya. In an another study, Negi *et al.* (1999) reported that fuel, fodder and timber trees cultivation is top most priority of the rural folk (55.9%), followed by horticultural species (41.1%) at low as well as high altitude villages. The fodder requirement in Kumaun hills is very high as each family maintains 5 to 6 cattles and hardly about 13% of total fodder requirements is met from agroforestry sector (Singh and Singh, 1987).

The consumption of biomass as fuel has been identified as one of the most significant causes of forest decline in many developing countries and according to one estimate, woodfuel accounts for over 54% of all global wood harvests per annum, suggesting a significant and direct role of woodfuel in forest degradation (Osei, 1993). Biomass is the main source of energy in Indian mountain villages and about half of all energy (commercial and biogas) consumed in India is used for cooking food. This is nearly double the energy (fossil, fuel, electricity) consumed by agriculture and the industrial sector. combined (Anonymous, 1982). Data about rural energy supply and consumption patterns are lacking and prejudices rural energy planning. At the same time, energy planners overlook this most essential energy use and planning priorities are usually set in favour of the industrial and agricultural sectors commercial energy demand rather than for domestic cooking. In the case of cooking, non-commercial sources of energy are even more crucial providing as much as 87% of the country's cooking energy requirements (Hall *et al.* 1982). But with dwindling forest resources and enforcement of new environmental laws by Government agencies has restricted fuelwood collection without provision of alternative sources of energy. Thus the very existence of the local people is being threatened (Bhatt *et al.*, 1994; Negi *et al.*, 1999). Past studies have witnessed that up to the beginning of 20th century, there was commercial exploitation of forests, which contributed significantly in the destruction of forest resource in the region (Negi *et al.* 1997). The demand for firewood is of the order of 300-330 Mt as against of 30-40 Mt production of firewood (Anonymous, 1985).

This gap between demand and supply could be bridged through extensive farming of firewood species.

In India, an estimated 196 million cattle and 80 million buffaloes, which account for 15% and 52% of world totals of these animals, are used for small-holder farm situations (Singh and Upadhyaya, 2001). Trees and shrubs often contribute a substantial amount of leaf fodder for these animals during 'lean' periods of fodder availability, through lopping/pruning of trees (Singh, 1982), popularly known as top feeds. Nevertheless, The synergies of tree-pasture association and their effects on livestock productivity have been evaluated to only a limited extent in India (Pathak, 2002). Rai *et al* (1999, 2001) have reported increase in land productivity through silvipastoral systems in the shallow red gravely soils under semiarid condition at Jhansi in central India, using trees such as *Acacia nilotica* var. *cupressiformis*, *Albizia lebbek*, *A. procera* and *Hardwickia binata*. Results of studies on performance of grass (*Cenchrus* sp.) and legume (*Stylosanthes* sp.) species grown under various tree species (*Albizia amara, A. lebbek*, *Acacia tortilis*, *Darbergia sissoo*, *L. leucocephala*, and *P. cineraria*) have also been reported from a number of places in India (Rao and Osman 1994; Sharma *et al.*, 1996; Pathak, 2002). Considerable information on silvipastoral systems under arid conditions is also available. In addition to indigenous tree species (e.g., *Prosopis cineraria* and *Z. nummularia*), the introduced species such as *A. tortilis*, *Dichrostactys cinerea*, and *Colophospermum mopane* have shown good performance in silvipastoral systems under such arid conditions (Ahuja, 1980). Biomass productivity of arid lands increased two to three times by replacing natural grass cover with *Cenchrus ciliaris* and introducing top feed (tree) species such as *Z. nummularia* and *Grewia tanax* under silvipastoral system (Sharma *et al.*, 1994). Nevertheless, information on the performance of livestock production under silvipastoral grazing conditions is meager (Rai, *et al.*, 1999).

So far fodder requirement and consumption in Kumaun Himalaya is concerned, Nautiyal and Nautiyal (1988) has reported that 372.25 tones of green fodder and 15 tones of dry fodder is annually required to rear 158 cattles in Kumaun hills. In an another study from Nainital hills of Central Himalaya, Arora and Porwal (2002) reported that on average there is 5.19 and 6.38 kg/ cattle/ day

consumption of tree fodder and grass fodder, respectively. Reynolds and Nautiyal (1987) however, reported 40-60 kg of green fodder consumption per household in Kumaun Himalaya. Negi and Todaria (1993) reported that projected per unit requirement of grass, tree fodder and fuelwood in Tehri district of Kumaun Himalaya as 3.52, 0.22 and 2.96 ton respectively. The study further revealed that there is deficit of fodder by 52% and fuelwood by 13%. Agrawal and Joshi (1993) reported that on average 14.0 kg/cattle/day fodder is required in outer range of Kumaun Himalaya.

Cropping Patterns.

In Kumaun Himalaya, the cropping patterns are built around two major cropping patterns, viz., *kharif* (April-October) and *rabi* (October-April) generally up to 1800 m asl and, at some locations, up to 2000 m asl. At higher altitude (> 2000 m asl), only summer season crops (April-October) are raised. Over 40 crop species and numerous farmer-selected land races comprising cereals, millets, pseudocereals, pulses, oilseeds, tubers, bulbs, and spices are cultivated in Kumaun Himalaya (Maikhuri *et al.*, 1997a). The huge diversity has been maintained through a variety of crop compositions, cropping patterns and crop rotations (Maikhuri *et al.*, 1996). Cropping pattern, crop composition, crop rotation and area under different crops during *kharif* and *rabi* seasons in the mountain villages of Kumaun have been reported by various workers (Semwal and Maikhuri, 1996; Bhatt and Chauhan, 2003; Singh, 1996; Swarup, 1993; Negi, 1992; Ralhan *et al.*, 1992; Negi, 1994; Saha *et al.*, 2007; Escobar *et al.*, 2007; Lorenzo *et al.*, 2007; Sharrow, 2007; Das and Chaturvedi 2008; McGraw, *et al.*, 2008; Sood and Mitchell 2009). The studies have shown that there is strong organic base of farming in Kumaun Himalaya. Random mixing in mixed crops in Kumaun Himalaya region differs from that in other parts of the central and eastern Himalaya where a regular arrangement of crops is common (Nautiyal *et al.*, 1998). Crop diversity in settled terraced agriculture of this region is considerably high compared to 4 to 8 crops in other sedentary upland agro-ecosystems studied in the Himalaya (Mishra and Ramakrishnan, 1982), and in the other mountainous region (Goland, 1993; Dougherty, 1994).

These set do not pertain to Kumaun as claimed. pl. put these in right context.

Traditionally four cropping systems are maintained in lesser Himalayas in Gahrwal. These are: (i) a kitchen garden around the homestead in which

seasonal vegetable and some fruits are grown for home consumption; (ii) an irrigated land cropping systems in which rice and wheat are the main crops; (iii) an upland and non-irrigated cropping systems, dominantly occupied by millets and pulses; and (iv) a summer camp cropping system, mainly devoted to pseudocereals (amaranth and buck-wheat) and beans (mainly kidney bean). This diverse cropping systems have been designed by the farmers in tune with varying micro-ecological niches suiting to the cultivation of specific crops and crop combinations (Singh, 1996). However, a standard feature of almost all hill agriculture systems is the practice of mixed cropping, once considered primitive by agronomist and soil scientists (Sanchez and Bual, 1976), and now suggested as a means to increase world food production (Andrews and Kassam, 1976).

Cropping and Yield Patterns in terms of Energy and Monetary Benefits

Agroforestry literature on tree-crop interactions is largely based on studies with young trees, with the exception of some studies of the parkland system and shaded perennial systems. One of the most widely reported systems is the *Prosopis cineraria* park lands in the arid and semiarid regions, mainly in Rajasthan and other western parts of the country (Shankarnarayan *et al.*, 1997; Puri *et al.*, 1994). Millet (*Lennisetum* spp.) and sorghum (*Sorghum bicolor*) crops growing within a 5 to 10 m radius around mature *P. cineraria* trees have been reported to yield two to three times more than crops growing adjacently but away from trees. This yield increase is attributed to soil fertility improvement under the trees (Shankarnarayan *et al.*, 1997), just as in the case of the *Faidherbia albida* system in West Africa (Boffa, 1999; Nair, 1989). However, various workers have recorded the reduced yield of agricultural crops in unmanaged tree fields. The extent of shading caused by trees and its impact on crops are also not adequately understood. Under *Acacia nilotica* trees northern India, wheat (*Triticum* sp.) yields were reduced by up to 60% (Puri and Bangarwa, 1992) and mustard (*Brassica* sp.) yields by up to 60% (Yadav *et al.*, 1993). In environments where seasonal rainfall (above ca 800 mm during the cropping season) or irrigation provides adequate water for crop growth, reduction of crop yields under trees could mainly be due to reduced light availability to the understorey crop. However, the light availability can be altered through management interventions

such as pruning or lopping the tree canopy, altering spatial geometries of the planting, etc.

Although considerable evidence exists that mature scattered trees in such environments are associated with improved soil nutrient supply in parkland systems, it is uncertain whether trees actually increase the total pool of nutrients in the system or simply re-distribute existing soil nutrients more effectively across the landscape (Kumar *et al.*, 1999; Nair *et al.*, 1999). If higher nutrient status under trees is due to nutrient redistribution, no net gain in production at the landscape scale can be expected. Unfortunately, not too many studies have sampled soil nutrients randomly over sufficiently large areas to test this hypothesis (Puri and Nair, 2004).

Several studies on tree management practices (lopping, pollarding, thinning, fertilizer application, and so on) and their effects on sub canopy light availability and yields of interplanted and overstory species are available (Kumar *et al.*, 2001; Shujauddin and Kumar, 2003). Planting of shade tolerant crops such as ginger (*Zingiber officinale*) and turmeric (*Curcuma longa*), and medicinal plants (such as *Pogostemon cablin*, and *Kaempferia galanga*) is another option to adjust to reduced light conditions (Kumar, 1999; Kumar *et al.*, 1999; Rao *et al.*, 2004). It is important to have a realistic understanding of the extent of crop yield changes on an overall area basis. In spite of the seemingly large yield variations under or near trees, the overall effect of trees on crop yields could be small because only a small proportion of the area is subjected to tree/crop interactions (Rao *et al.*, 1998). Considering a scattered-tree system that contains 20 trees/ha with each tree affecting crops over a 100 m^2 area, if the trees increase or decrease crop yields by 50% over that area, the overall yield of the system will be only 10% higher or lower than that of sole crop (Puri and Nair, 2004).

In Kumaun Himalaya, lot many tree species are cultivated in or around agricultural fields in rainfed agriculture. Trees like *Celtis australis*, *Terminalia* spp., *Albizia* spp., *Ceiba pentandra*, *Toona ciliata*, *Quercus leucotrichophora* attain a height growth more than 30 m. Rest of the species attain a height between 10 to 15 m. The crown is managed through lopping of fodder particular during lean season. As such very few studies have been conducted on effects of

trees on crop yield from Kumaun Himalaya, however, on average, 20-30% agricultural losses have been reported due to trees (Swarup, 1993; Bhatt and Chauhan, 2003).

The energy efficiency (output: input) is an indicator of ecological efficiency of a given agricultural system (Pimentel, 1973; Leach, 1976; Mitchell, 1979). It is suggested that hill agroecosystems with traditional crops are ecologically and economically viable and still have the potential to support the food requirements of a growing population in the region, provided it is developed on a value based system through appropriate technological inputs based on indigenous knowledge to enhance the agronomic yield and simultaneously integrating the component of value addition (Ramakrishnan *et al.*, 1994; Roa and Saxena, 1994). Enormous work on energetic/eco-energetic of hill agro ecosystems have been carried out by various workers in different parts of the Himalaya (Panday and Singh, 1984; Sharma, 1991; Ralhan *et al.*, 1992; Semwal and Maikhuri, 1996; Bhatt and Chauhan, 2003; Negi and Singh, 1990; Mishra and Ramakrishnan, 1981, 1982; Rai, 1993; Houpii, 1986; Mitchell, 1979). Similar studies have also been made for north eastern part of India (Toky and Ramakrishnan, 1982). Maikhuri *et al* (1996) reported that most of the traditional crops cultivated in the higher Himalaya in mono- or mixed-cropping exhibited higher energy and monetary efficiencies than those grown at middle and lower altitudes. Similar observations have also been made by Sharma (1991) and Negi (1994).

So far total energy inputs in an agro-ecosystems of Kumaun Himalaya are concerned, farm yard manure contributes significantly more (> 50%) than any other input (including human labour, bullock labour, mechanical labour and seeds etc). Traditionally, this is the main source for replenishing soil fertility after crop harvest, other sources being crop rotations and fallowing. Human, particularly women, and bullock labour are the next important inputs in the agro-ecosystem of the region (Semwal and Maikhuri, 1996; Maikhuri *et al.*, 1996). Greatest human energy (> 45%) is consumed in weeding. Mixed cropping has been found more productive per unit of area. Moreover the productivity of the *kharif* season crops has been recorded higher than the *rabi* seasons crops particularly in the rainfed agriculture. Energy input and output ratio in Kumaun Himalaya was recorded in the range of 2.6 to 3.99 for agroforestry systems of

Kumaun Himalaya (Singh *et al.*, 1997). Nautiyal *et al.* (1998) reported output: input ratio of 0.63 to middle altitude villages of Kumaun Himalaya. In another study, Semwal and Maikhuri (1996) reported a range of output: input ratio for 2.60 to 5.80 to foothills of Kumaun.

RESULTS

380-500 m asl

Tables 8 to 12 represents the different cropping patterns, crop combinations, labour inputs for various agricultural activities, fertilizer inputs, eco-energetic analysis and cost- benefit analysis at 380-500 m asl in control plots, *i.e.*, without integrated ~~of~~ trees.

On an average, seven different crops or crop combinations were grown as summer crops and six nos. of crops during winters. Ginger, however, was grown on annual basis. Wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*) were the major winter cereal crops, whereas paddy (*Oryza sativa*), barnyard millet (*Echinochloa frumentacea*) were the major summer crops. Wheat was grown either as a sole crop or intercropped with mustard (*Brassica campestris*) and pea (*Pisum sativum*). Barley was grown in association of lentil (*Lens esculantus*) and mustard. During summer, finger millet (*Eleusine coracana*) was cultivated with cowpea (*Vigna unguiculta*) and black gram (*Vigna mungo*). Similarly, maize (*Zea mays*) was grown in association of green gram (*Vigna radiata*). Rest of the crops large was cultivated as a monocrop. What value is more for winter crops.

On an average, 1553 and 1303 hrs of human labour was required for per ha cultivation during winter and summer crops, respectively, irrespective of crops or crop compositions. Females contributed respectively, 61.0 and 49.0% of the total human labour during summer and winter crops. On an average, male contributed 25.0 and 26.0% of the total labour input to summer and winter crop's cultivation. Rest was shared by child (below the age of 12 years) (fig. 1). Total human labour input (hrs/ha/yr) was recorded highest (2106.7) for onion cultivation followed by garlic (1889.3). Among various crop combinations, minimum human labour input was required for sesame cultivation (735.6 hrs/ha/yr). The bullock labour was required highest (140.3 hr) in kidney bean (*Phaseolus vulgaris*) cultivation followed by wheat (136.6) (fig.2). The bullock labour was required only 119.0 and 102.0 hrs/ha for winter and summer crops, which indicated that human labour was consumed 12 to 13-fold higher for per hectare cultivation compared to bullock labour. Barley, finger millet and barnyard millet are grown only in rainfed agriculture. Moreover the land is left fallow after cultivation of these two crops (Table 8).

Ploughing and leveling operations during summer cropping are exclusively conducted by the males. They also contribute labour for hoeing/weeding, irrigation, manuring, sowing/transplanting, harvesting, threshing and transportation. Bullock labour was mainly used for ploughing and leveling. However, the bullock labour was also employed for threshing of wheat and barley. Similarly during winter cropping, male labour is engaged for ploughing, leveling, puddling, hoeing/weeding (particularly in barnyard millet and finger millet cultivation), irrigation, threshing and transportation of the grains. Females contributed for majority of the agricultural operations (fig.3).

Seed rate input of various agricultural crops has been given in Table 9. Tuberous/rhizomatous crops had high seed input rate (Kg/ha) compared to cereal/pulses/oil seed crops. On an average, the major crops like wheat, barley, barnyard millet, finger millet, maize and paddy, respectively, had the seed rate of 129.0, 48.9, 12.6, 4.0, 44.4 and 40.3 kg/ha. Farmyard manure (FYM) is the main source of fertilizer either to winter or summer crops. The range of FYM application varied from 9.3 (for garlic) to 21.3 q/ha (for paddy). Besides, at this particular altitude, urea and DAP was also used as fertilizer for wheat cultivation either as a sole crop or in association of mustard and pea. Farmers used higher amount of FYM (20.0 q/ha/yr) for cultivation of wheat, MCC1, kidney bean, paddy and ginger; and the amount is reduced almost by 50% in case of millet's cultivation (Table 9).

⇒ It is too high a value [illegible] the state average for rainfed crop/ irrigated crops

Crop productivity (q/ha) has been shown in Table 10. On an average, the productivity of wheat was recorded 34.0 q. Paddy showed the average grain yield of 30.5 q/ha. Maize yield was recorded to be 14.8 q/ha. The grain productivity of staple food crops like barley, barnyard millet and hog millet was recorded to be 25.3, 15.9 and 17.3 q/ha. Finger millet was grown in the mixed crop composition and the average productivity was 6.03 q/ha. The crop byproduct of all the aforesaid crops has been used as a fodder for cattle. The crop byproduct yield was respectively 47.2, 34.5, 36.3, 15.1, 28.8, 33.4 and 26.0 q/ha for wheat, barley, barnyard millet, finger millet, maize, paddy and hog millet.

Total energy input (MJ/ha/yr) of human labour for various agricultural operations showed a range of 355.7 (sesame cultivation) to 861.5 (maize + green gram). Human energy consumption was found comparatively low for

barley, barnyard millet, hog millet and ginger cultivation (range 450.2 to 544.3). Most of the agricultural operations belonged to heavy works. Mixed crop composition or mono cropping did not exhibit marked variation in total energy requirement of human labour.

Comparative energy budget for various agricultural crops has been shown in Table 11. Among various inputs, it has been observed that more than 90% energy input was contributed by FYM, irrespective of crops and crop composition. The annual energy input (MJ/ha/yr) of human labour, bullock labour and seed was, respectively, 1073.8, 1135.0 and 1848.4, irrespective of crop and crop composition. On the other hand, the energy output was, respectively, 49.2, 50.4 and 0.4% through grain/vegetable yield, crop byproduct and fodder from weeds and grasses of the bunds. Among various winter crops, total energy input was recorded highest for crop composition of wheat + mustard + pea (39345.0 MJ/ha/yr) so as to total energy outputs (126716.2 MJ/ha/yr). In case of summer crops, the annual energy input was recorded highest (40140.9 MJ/ha) for kidney bean cultivation, followed by ginger (33974.1 MJ/ha) and paddy (33378.7 MJ/ha). Among various summer and winter crops, lowest energy input was recorded for hog millet cultivation (1186.1 MJ/ha). The total energy output for summer crop, however, was recorded highest for paddy (97949.2 MJ/ha) followed by MCC4 (84116.5 MJ/ha) and MCC3 (78641.1 MJ/ha).

Among winter crops, energy output: input ratio was recorded highest (3.70) to MCC2, followed by MCC1 (3.2). Lowest output: input ratio, however was recorded to garlic cultivation (1.05). Although hog millet showed the very high output: input ratio (55.24) but it cannot be compared with other crops as it is a intermediate short rotational (2 to 3 month) crop, grown in irrigated fields before transplanting of rice. Since no fertilizer is applied for its cultivation, the net input was significantly low for its cultivation compared to other summer or winter crop thereby indicated very high output: input ratio. Among various summer crops, MCC4 exhibited the highest output: input ratio (4.52), followed by MCC3 (3.73) and barnyard millet (3.70). Kidney bean cultivation, however, exhibited the lowest output: input ratio (1.41).

The monetary input and output has also been worked out. The prevailing rates for seed, fertilizer, human and bullock labour alongwith price of grain,

green and dry fodder etc has been shown in Table 7 in methodology section. Based on crop rotations, the total monetary input has been worked out as Rs. 23,665.0/ha. On an average, the monetary input was highest (62.3% for the total input) through human labour. Bullock labour, FYM and seed, respectively, showed 14.8, 12.4 and 10.4% of the total monetary inputs. So far total output monetary was concerned it has been recorded as Rs. 43394.0/ha. Inter-comparing the monetary input and output during different cropping seasons, it has been recorded that the monetary input was, respectively, 16780.0 and 11783.0 Rs/ha to winter and summer crops with monetary output was Rs. 38397.0 and Rs. 15755.0 accordingly to the same crops. Net monetary output: input ratio was 2.2 and 1.5, respectively, to winter and summer crops. Among various winter crops, onion cultivation exhibited highest output: input ratio (3.5), followed by potato (2.9) and garlic (2.6) cultivations. Among summer crops, kidney bean had highest output: input ratio (2.90), followed by MCC3 (1.6). The annual crop ginger showed the monetary output: input ratio of 2.8 (Table 12).

Table 13 depicts the data on phytosociological parameters such as relative frequency, relative density, relative dominance and IVI of different tree-crops found in different agroforestry systems (AFS). In agrisilvi (AS) system, *Grewia optiva* exhibited highest values of relative frequency, relative density and relative dominance, which has resulted to have highest IVI, whereas *Celtis australis* was having lowest value in all the respects. Among various fruit tree species, *Citrus aurantifolia* exhibited relatively higher values of relative frequency, relative density as well as IVI in agrihorti (AH) system, whereas lowest values in all respect were recorded in *Musa paradisica*. Relative dominance in this AFS was highest in *Mangifera indica* although, it did not have much influence on IVI value. Among the silvicultural component of agrihortisilvi (AHS) system, *Dalbergia sissoo* had the highest rate of occurrence with relative dominance, which has resulted to have highest IVI. A lowest value of relative frequency and relative density, however, was observed in *Ficus hispida*, which influenced to bear lowest IVI in this component of AHS system. Among the horticultural component, highest values of relative frequency, relative density and relative dominance were observed in *M. indica*, which boosted the IVI of this particular component in AHS system. Lowest values of relative frequency and relative density were observed in *Citrus maxima*, although, due to the lowest

relative dominance in the *Prunus persica*, lowest IVI was observed in this component of this particular AFS.

As many as 16 multipurpose tree species (MPTS) and 09 fruit trees species were cultivated by the farmers in or around agricultural fields in rainfed situation. Fuel, fodder, timber and fruit yield has been recorded for each MPTS and fruit tree species. The total tree fodder yield was recorded to be 17.6 and 16.4 q/ha, respectively, in AS and AHS systems. Similarly, the firewood yield was recorded to be 8.1 and 7.4 q, respectively, from AS and AHS system. The fibre yield (extracted from *G. optiva*) was 0.41 kg/tree/yr. Among various MPTS, the average fodder yield was recorded highest (24.1 kg/tree/yr) in *Boehmeria rugulosa* and lowest (2.0 kg/tree/yr) in *Leucaena leucocephala*. Similarly the fuelwood yield was also recorded highest in *B. rugulosa* (11.0 kg/tree) and lowest (1.3 kg/tree) in *L. leucocephala*. Species like *Albizia lebbek, B. rugulosa, D. sissoo, Ougeinia oojeinensis* and *Toona ciliata* were also used as timber species. On an average, the timber volume per tree was recorded highest (1.03 m^3) in *D. sissoo*, followed by *T. ciliata* (0.82 m^3) and *O. oojeinensis* (0.81 m^3). Lowest timber volume, however, was recorded in *B. rugulosa* (0.10 m^3). The total timber production was also recorded highest in *D. sissoo* (17.82 m^3/ha) and lowest (2.60 m^3/ha) in *B. rugulosa* (Table 14).

Among various MPTS, *B. rugulosa*, *Ficus auriculata*, *F. cunia, F. hispida, G. optiva, Melia azedarach* have been cultivated in both AS and AHS systems. On an average, 148 nos. of trees are cultivated per hectare of land in AS system. Similarly in AHS system, the total density of trees was recorded to be 241 per hectare, irrespective of species. The tree density in AH system was recorded to be 114 per hectare of land. Inter-comparing the tree density of MPTs at species level, maximum density was noticed for *G. optiva* (32.0), followed by *Mallotus philippensis* (23.0) whereas lowest tree density was recorded for *Celtis australis* (1.0). Similarly in case of AH system, tree density was highest for *Citrus aurantifolia* (32.0), followed by *Mangifera indica* (27.0). Among various fruits tree species lowest density, however, was recorded for *Musa paradisica* (5.0).

Tree fodder yield ranged from 16.4 to 17.6 q/ha/yr at lowest altitude. Similarly, the timber yield was 16.2 and 22.8 m^3/ha/yr, respectively, in AS and AHS systems. Firewood productivity ranged from 7.4 to 8.1 q/ha/yr whereas, fruit

yield was 19.4 and 23.2 q/ha/yr, respectively, in AHS and AH AFS. The productivity of the grass from bunds of agricultural fields ranged from 1.3 to 1.4 q/ha/yr (Table 14.1). .

Tables 15 to 19 represents the different cropping patterns, crop combinations, labour inputs for various agricultural activities, fertilizer inputs, eco-energetic analysis and cost benefit analysis of AS AFS at 380 to 500 m asl. On an average, six different crops or crop combinations were grown as summer crops and three nos. of crops during winters in AS system. Wheat and barley were the major winter cereal crops, whereas, paddy and barnyard millet were major summer crops. Wheat was grown either as a sole crop or intercropped with mustard and pea. Barley however was grown in association of lentil and mustard. During summer, finger millet was cultivated with cowpea and black gram. Similarly, maize was grown in association of green gram. Rest of the crops was cultivated as a mono crop. On an average, combinations were same either on control (without tree) or agroforestry plots.

Total energy input (MJ/ha/yr) of human labour for various agricultural operations showed a range of 396.2 (sesame cultivation) to 866.7 (maize + green gram). The human energy consumption was also found comparatively low for cultivation of barnyard millet and hog millet (range 473.2 to 562.6). Most of the agricultural operations belonged to heavy works. Mixed crop composition or mono cropping did not exhibit marked variation in total energy requirement of human labour (fig. 4).

Among winter crops, MCC 1 required highest human labour input (1588.4 hrs/ha). Similarly, MCC 4 followed by MCC 3 had highest labour input compared to other crops. Minimum human labour input, however, was required for sesame cultivation (843.0 hrs/ha/yr). The bullock labour was required highest (132.1) in MCC 1 cultivation followed by wheat (126.7). On an average, 1375.2 and 1388.0 hrs of human labour was required for per hectare cultivation during winter and summer crops, respectively, irrespective of crops or crop compositions. Females contributed respectively, 57.0 and 43.0% of the total human labour during summer and winter crops. On an average, male contributed 25.0 and 20.0% of the total labour input to summer and winter crop's cultivation. Rest was shared by child (fig. 5). The bullock labour was required only 120.0 and 89.0 hrs/ha,

respectively, for winter and summer crop's cultivation. Barley, finger millet and barnyard millet were grown only in rainfed agriculture (Table 15).

Ploughing and leveling operations during winter cropping are exclusively conducted by males. They also contributed labour for hoeing/weeding, irrigation, manuring, sowing, transplanting, harvesting, tree lopping, threshing and winnowing and transportation/carrying. Ploughing operation consumed maximum bullock labour (59.0 hrs/ha), followed by threshing (45.0 hrs/ha). During summer cropping, male labour is engaged for ploughing, leveling, puddling, hoeing/weeding (particularly in paddy, barnyard millet and finger millet cultivation), irrigation, manuring, threshing and transportation of the grains. Females contributed in majority of the operations. Among various crop's cultivation, irrigated paddy required maximum human and bullock labour compared to other crops (fig.6.).

Seed rate input of various agricultural crops has been given in Table 16. Wheat and barley crops showed high seed rate input (kg/ha) compared to other seed crops. On an average, the major crops like wheat, barley, barnyard millet, finger millet, maize, paddy, and hog millet, respectively showed the seed rate of 120.1, 45.5, 11.7, 3.7, 41.3, 37.5 and 13.0 kg/ha. Farmyard manure (FYM) was the main source of fertilizer either to winter or summer crops. The range of FYM applications varied from 10.5 (for sesame) to 19.8 q/ha (for paddy). Besides, urea and DAP was also used particularly for Wheat cultivation either as a sole crop or in combination of mustard and pea. Farmers used higher amount of FYM (17-20 q/ha) for cultivation of wheat, MCC-1, MCC-2 and paddy; and the amount is reduced almost by 50% in case of millet's cultivation.

Crop productivity (q/ha) in AS AFS has been shown in Table 17. On an average, wheat productivity was 30.6 q/ha. Paddy showed the average grain yield of 27.4 q/ha. Maize yield was recorded to be 13.3 q/ha. The grain productivity of staple food crops like barley, barnyard millet and hog millet was recorded to be 22.7, 11.5 and 15.5 q/ha, respectively. Finger millet was grown in the mixed crop composition and the average productivity was 5.43 q/ha. The crop byproduct yield was respectively 42.6, 30.7, 31.8, 13.6, 25.0, 30.1 and 23.5 q/ha for wheat, barley, barnyard millet, finger miller, maize, paddy and hog millet.

Comparative energy budget for various agricultural crops has been shown in Table 18. Among various inputs, it has been observed that more than 90% energy input was contributed by FYM, irrespective of crops or crop composition. The annual input (MJ/ha/yr) through human labour, bullock labour and seed was, respectively, 1175.1, 1084.1 and 1333.1, irrespective of crop and crop compositions. On the other hand, the energy output was respectively 35.3, 50.0, 0.3, 4.5 and 9.9% through grain, crop byproduct, fodder from weed and grasses of the bunds, fodder from agroforestry trees and fuelwood from agroforestry trees.

Among various winter crops, total energy input was recorded highest for crop composition of wheat + mustard + pea (36655.39 MJ/ha/yr) so as to total energy output (125353.7 MJ/ha/yr). In case of summer crops, the annual energy input was recorded highest (31104.1 MJ/ha/yr) for paddy cultivation. Among various summer and winter crops, lowest energy input was recorded for hog millet cultivation (1100.0 MJ/ha/yr). Among various summer crops, the total energy output was recorded highest for paddy (100323.9 MJ/ha/yr), followed by MCC-3 (94741.4 MJ/ha/yr) and barnyard millet (89074.4 MJ/ha/yr). Among winter crops, energy output: input ratio was recorded highest (3.9) to MCC 2, followed by wheat (3.4). Lowest output: input ratio, however, was recorded to MCC 1 cultivation (3.4). Among summer crops, MCC 4 exhibited the highest output: input ratio (5.0), followed by MCC 3 (4.8) and barnyard millet cultivation (4.5). Sesame cultivation, however, exhibited the lowest output: input ratio (2.5).

The monetary input and output has also been worked out. The prevailing rates for seed, fertilizer, human and bullock labour alongwith price of grain, green and dry fodder, and fuelwood etc. has been shown in Tables 7 to 7.3 in methodology section. Based on crop rotation, the total monetary input has been worked out as Rs. 22,679.0/ha. On an average, the monetary input was highest (69.9% of the total input) through human labour. Bullock labour, FYM, and seed, respectively, showed 14.8, 12.2 and 3.1% of the total monetary inputs. So far total monetary output was concerned, it has been recorded as Rs. 38,189/ha, irrespective of cropping seasons, and 73.9% of the total output was contributed by grain productivity. Rest was shared by green fodder (bund grass and tree leaves), dry fodder and fuelwood, irrespective of cropping patterns and cropping seasons. Inter-comparing the monetary input and output during different

cropping seasons, it has been recorded that the monetary input was, respectively, 14,774 and 11,512 Rs/ha to winter and summer crops. The net monitory output: input ratio was 1.6 and 1.2, respectively, to winter and summer crops. Among various winter crops, MCC 2 cultivation exhibited the highest output: input ratio (1.7), and MCC 1 the minimum (1.5). Among summer crops, MCC 3 had highest output: input ratio (1.8), followed by MCC4 (1.5) (Table 19).

Table 20 to 24 represents the different cropping patterns, crop combinations, labour input for various agriculture activities, fertilizer inputs, eco-energetic analysis and cost-benefit analysis of AH agroforestry system. Total energy input (MJ/ha/yr) of human labour for various agricultural operations showed a range of 541.8 (barnyard millet cultivation) to 805.3 (paddy cultivation). Most of the agricultural operations belonged to heavy works. Mixed crop composition or mono cropping did not exhibit marked variation in total energy requirement of human labour (fig. 7).

The bullock labour (hrs/ha) was required highest (123.4) in wheat cultivation followed by MCC 3 (118.5) (fig. 8). On an average, three different crops or crop combinations were grown as summer crops and two nos. of crops during winters. Wheat and barley were major winter cereal crops, whereas paddy and barnyard millet were major summer crops. Wheat was grown as a sole crop, whereas barley was intercropped with lentil and mustard. During summer, finger millet was cultivated with cowpea and black gram. Fig. 9 reveiled that the total human labour input (hrs/ha) was recorded highest (1829.1) for paddy cultivation, followed by MCC 3 (1582.5). Among various crop combinations, minimum labour input was required for barnyard millet cultivation (1113.5 hrs/ha). On an average,. 1344.3 and 1508.4 hrs of human labour was required for per ha cultivation during winter and summer crops, respectively, irrespective of crops or crop compositions in AH system. Female contributed, respectively, 74.3 and 55.5% of the total human labour during winter and summer crops. On an average, male contributed 21.7 and 19.4% of the total labour input to winter and summer crop's cultivation. The bullock labour was required only 110.2 and 107.9 hrs/ha for winter and summer crops (Table 20).

Ploughing and leveling operations during summer cropping were exclusively conducted by the males. They also contributed labour for

hoeing/weeding, irrigation, manuring, sowing/transplanting, harvesting, fruit picking, threshing winnowing and transportation. Bullock labour was mainly used for ploughing, leveling and puddling. However, it was also employed for threshing of wheat, barley and finger millet.

Seed rate input of various agricultural crops and fertilizer consumption has been given in Table 21. On an average, the seed rate for wheat, barley, barnyard millet, finger millet and paddy was, respectively, 116.7, 44.2, 11.4, 3.6 and 36.5 kg/ha. The range of FYM application varied from 15.3 (for MCC 3) to 20.9 q/ha (for paddy). Besides, at this particular altitude, urea and DAP was also used for wheat cultivation. FYM was also used in fruit trees @ 3.0 kg/tree with highest in *Citrus aurantifolia* (0.97 q/ha) and lowest (0.15 q/ha) in *Musa paradisica*.

Crop productivity (q/ha) in AH system has been shown in Table 22. The average wheat productivity was 28.7 q/ha. Paddy showed the average grain yield of 26.5 q/ha. The grain productivity of staple food crops like barley, barnyard millet and finger millet was recorded to be 20.8, 10.5, 4.5 q/ha, respectively. Productivity of important pulses like lentil, cowpea and black gram 1.2, 4.2, and 3.1 q/ha. The crop byproduct yield was, respectively, 38.7, 27.9, 29.7, 12.2 and 28.2 q/ha for wheat, barley, barnyard millet, finger millet and paddy.

Comparative energy budget for various agricultural crops has been shown in Table 23. Among various inputs, it has been observed that FYM alone contributed 93.0% energy input, irrespective of crops or crop compositions. The annual energy input of human labour, bullock labour and seed was, respectively, 839.7, 824.2 and 1000.4, irrespective of crop and crop composition. On the other hand, the energy output was, respectively, 31.2, 42.3, 0.4, 26.1% through grain, crop byproduct, fodder from weed and grasses of the bunds, and fruits. Among various winter and summer crops, total energy input was recorded highest (36898.4 MJ/ha/yr) for wheat cultivation, followed by paddy (32668.1 MJ/ha/yr). Highest energy output was recorded for MCC 2 (121907.6 MJ/ha/yr) and lowest in MCC 3 (94341.0 MJ/ha/yr). Energy output: input ratio was recorded highest to barnyard millet and MCC3 (3.9 for both the crops). Lowest value of output: input ratio was recorded in wheat (3.1) cultivation.

Based on crop rotations, the total monetary input has been worked out as Rs. 17,118/ha.. On an average, the monetary input was highest (65.3% for the total input) through human labour. Bullock labour, FYM and seed, respectively, contributed 15.7, 14.8, 2.9% to the total monetary inputs. So far total monetary output was concerned, it has been recorded as Rs. 37,367.0/ha, and 41.1% of the total output was achieved through grain yield. Interestingly, 53.5% of the total monetary output was obtained through fruits. Inter-comparing the monetary input and output during different cropping seasons, it has been recorded that the monetary input was, respectively, 14,201 and 13,356 Rs/ha to winter and summer crops with the net monetary output of Rs. 29,895 and Rs. 29,892/ha accordingly to the same crops. The net monetary output: input ratio was 2.2 and 2.3, respectively, to winter and summer crops. Among various winter and summer crops, MCC 2 cultivation exhibited highest output: input ratio (2.7) followed by barnyard millet (2.5). Lowest output: input ratio was recorded for wheat cultivation (Table 24).

Table 25 to 29 represents the different cropping patterns, crop combinations, labour inputs for various agricultural activities, fertilizer inputs, eco-energetic analysis and cost benefit analysis of AHS agroforestry system at 380-500 m asl. Out of total cultivated area, *i.e.*, 20.3 ha, AS, AH and AHS systems were practiced, respectively, over 15.3, 1.7 and 2.8% area. Compared to AS and AH systems, seasonal vegetables are mainly cultivated in AHS system.

While ginger, turmeric and elephant ear were grown on annual basis; bulb and tubers like onion, garlic and potato and leafy vegetables like cabbage, mustard leaf and spinach were the major vegetable crops. Major summer vegetables include the cultivation of brinjal, chilli, tomato and ladies finger in AHS system.

Fig. 10 exhibited that the total human labour input (hrs/ha) was recorded highest (2085.3) for onion cultivation followed by garlic (1866.6). Among various crop combinations, minimum human labour input was required for snake guard cultivation (677.1 hrs/ha). The bullock labour, however, was required highest (112.7 hrs/ha) in MCC-3 cultivation and lowest (85.2 hrs/ha) in garlic cultivation. On an average, 1494.8, 1038.1 and 1246.2 hrs of human labour was required for

per ha cultivation during winter, summer and annual crops, respectively, irrespective of crops or crop compositions. Females contributed, respectively, 83.4, 92.3 and 65.5% of the total human labour input during winter, summer and annual crops. The bullock labour was required only 41.4, 15.3 and 89.9 hrs/ha for winter, summer and annual crops in AHS system (Table 25).

In AHS system, male labour is mainly engaged for ploughing and leveling. However, hoeing/ weeding, harvesting, threshing and transportation during summer crops in also showed by male labour. Rest of the operation were exclusively conducted by female and child labour. During annual cropping, male and bullock labour was engaged for ploughing, leveling, sowing/transplanting in ginger, turmeric and elephant ear. Both male and female labour equally contributed for annual crop's cultivation (fig. 11).

Seed rate input of various agricultural crops/vegetables has been given in Table 26. Potato, garlic, turmeric, ginger and elephant ear, respectively, showed the seed rate of 1287.4, 208.1, 825.0, 693.7, and 1028.0 kg/ha. On an average, the major transplanted vegetable crops like onion, cabbage, brinjal, chilli and tomato, respectively, had the seed rate of 8.7, 0.6, 0.6, 0.9, and 0.6 kg/ha. Other vegetable crops exhibited the seed rate of $\geq$ 3.0 kg/ha. The range of FYM application varied from 10.1 (for snack gourd) to 24.5 q/ha (for mustard leaf). Farmers used higher amount of FYM (20q/ha/yr) for cultivation of all the winter and annual crops, and the amount are reduced almost by 50% in case of summer crop/vegetable cultivation. FYM was also used in fruit trees @ 3.0 kg/tree with highest in *Psidium guajava* (2.1 q/ha) and lowest (0.31 q/ha) in *Citrus maxima*.

Crop productivity (q/ha) in AHS has been shown in Tables 27 and 27.1. On an average, the grain productivity of barley, finger millet and barnyard millet was recorded as 19.2, 4.0 and 7.9 q/ha, respectively. The productivity of staple pulse crops like lentil, cowpea and black gram was 1.3, 4.1 and 3.1 q/ha, respectively. The crop byproduct of all the aforesaid crops has been used as a fodder for cattle. The crop byproduct yield was, respectively, 25.6, 9.3 and 20.7 q/ha for barley, finger millet and barnyard millet. Among vegetables, highest productivity was recorded for cabbage (151.0 q/ha), followed by elephant ear (134.2 q/ha), potato (130.0 q/ha), onion (115.0 q/ha), and mustard leaf (111.1

q/ha). The productivity of ginger, turmeric and garlic was, respectively, 40.1, 61.2 and 31.2 q/ha. Fenugreek, however, showed the lowest productivity (5.7 q/ha).

Total energy input (MJ/ha) of human labour for various agricultural operations showed a range of 266.9 (snake gourd cultivation) to 857.7 (onion cultivation) in AHS system. Most of the agricultural operations belonged to heavy works, mostly carried out by the females (fig. 12).

Comparative energy budget for AHS system has been shown in Table 28. Among various inputs, it has been observed that more than 93% energy input was contributed by FYM, irrespective of crops/vegetables and crop composition. The annual energy input (MJ/ha), of human labour, bullock labour, and seed was, respectively, 987.6, 577.9 and 1585.3, irrespective of crops. On the other hand, the energy output was, respectively, 37.3, 21.3, 0.4, 5.6, 11.8 and 23.6% through grain/vegetable yield, crop byproduct, fodder from weed and grasses of the bunds, fodder, and fruit from agroforestry trees. Among various, total energy input was recorded highest (36703.5 MJ/ha/yr) for mustard leaf cultivation, followed by ginger (36694.9 MJ/ha/yr). Lowest energy input was recorded in snake gourd cultivation (15127.5 MJ/ha/yr).

The total energy output for winter, summer and annual crops, however, was recorded highest for turmeric (144515.7 MJ/ha) cultivation, followed by ginger (112197.9 MJ/ha) and lowest in snake gourd (31444.7 MJ/ha) cultivation. Energy output:input ratio was recorded highest (4.1) to turmeric, followed by MCC 3 (3.6). Lowest output: input ratio, however, was recorded to fenugreek (1.1) cultivation.

The monetary input and output has also been worked out. Based on crop rotations, the total monetary input has been worked out as Rs. 22,556/ha. On an average, the monetary input was highest through human labour (64.1% for the total input). Bullock labour, FYM and seed, respectively, showed, 9.9, 14.3, and 11.7% of the total monetary inputs. So far total monetary output was concerned, it has been recorded as Rs. 61,553/ha and 66.1% of the total output was obtained through grain/vegetables and rest in shared by green and dry fodder, fuelwood and fruits, irrespective of cropping patterns. Inter-comparing the monetary input and output during different cropping seasons, it has been recorded that the monetary input was respectively, 13,995, 8679 and 17,475

Rs/ha to winters, summer and annual crops. Among various winter crops, highest output: input ratio of monetary returns was recorded for cabbage cultivation (5.2), followed by onion (3.3). Lowest output: input ratio was recorded in fenugreek cultivation (2.0). Similarly among the summer crops, pumpkin cultivation in AHS showed the highest output: input ratio (6.2), followed by bottle gourd (5.4), snake gourd (5.2) and bitter gourd (5.1). Lowest output: input ratio was recorded for barnyard millet cultivation (1.4). The range of output: input ratio for annual crops varied from 3.2-4.0. The monetary output was Rs. 39,515, 31,219 and 65,426, accordingly, to winter, summer and annual crops. The monetary output: input ratio was 2.9, 3.9 and 3.7, respectively, to winter, summer and annual crop's cultivation (Table 29).

Table 30 depicts the data on comparative energy budget of different agroforestry systems including control. On an average, for all the systems including control, the energy input was >.90% through FYM and fertilizers, and rest was shared by seed, human and bullock labour. Inter-comparing the values between systems, no significant variations have been recorded however, the total energy input was highest (50399.0 MJ/ha/yr) for AHS and lowest (37470 MJ/ha/yr) for AH system, respectively. So far outputs were concerned, grain/vegetable yield contributed 31.0-37.3% in different AFS compared to 49.0% in control. It clearly indicated that the grain/vegetable productivity was higher in control plots compared to agroforestry plots. Output through crop residue was also recorded high in control (50.4%) and lowest (21.3%) in AHS system. The fruit yield partitioned 23.6-26.1% of the total energy output in AH and AHS systems. Similarly the fuelwood yield from the trees cultivated in AS and AHS systems contributed 9.9-11.8% of the total energy output, whereas, foliage from agroforestry trees showed 5.0% of the total outputs. The total energy output, however, was recorded highest to AS system (165283.5 MJ/ha/yr) and lowest (122566.0 MJ/ha/yr) to AHS system. The output: input ration has been worked out keeping in view the different crops and crop byproduct yield. Consideration of the grain/vegetable productivity, the output: input ratio was highest (1.5) in control and lowest in AHS system (0.9). Calculating the total biological yield, the output: input ratio was highest (4.0) in AS system, followed by AH system (3.4). AHS system, however, showed lowest output: input ratio (2.4).

Table 8. Total labour input (hrs/ha/yr) for different crops grown at 380 to 500 m asl without integration of trees (control).

Season	Crop components	Human labour				Bullock labour
		Man	Women	Child	Total	
Winter	MCC-1	447.4	1128.7	-	1576.0	141.9
	Wheat	539.83	725.3	76.3	1341.4	136.6
	MCC-2	107.5	981.4	42.9	1131.9	107.5
	Onion	339.3	1301.6	465.8	2106.7	99.1
	Garlic (bulb)	350.9	957.8	580.6	1889.3	106.7
	Potato (tuber)	554.0	542.3	174.8	1271.1	119.8
Summer	Sesame	69.12	558.9	107.5	735.6	69.1
	Barnyard millet	364.5	462.8	146.6	973.9	100.5
	MCC-3	312.6	725.7	399.9	1438.2	131.1
	MCC-4	518.9	693.7	483.8	1696.6	75.3
	Paddy	317.6	875.3	712.5	1905.4	126.3
	Hog millet	245.0	511.9	341.0	1097.9	74.4
	Kidney bean	554.9	613.9	104.9	1273.7	140.3
Annual	Ginger (rhizome)	469.1	482.0	72.1	1023.2	99.9

Bund area per ha cultivated land was 0.032 ha; Bullock = 1 Pair

MCC = Mixed Crop Composition; MCC-1 = Wheat + mustard + pea; MCC-2 = Barley + lentil + mustard, and MCC-3 = Finger millet + cowpea + black gram and MCC-4 = Maize + green gram.

CROP ROTATION

MCC-1----------Hog millet---	Paddy------------	1 year (Irrigated)
Wheat ----------------------	MCC-4 ----------	1 year (Irrigated)
MCC-2 ----------------------	Sesame ----------	1 year (Rainfed)
MCC-3 ----------------------	Fallow ----------	1 year (Rainfed)
Barnyard millet ------------	Fallow ----------	1 year (Rainfed)
Bulb & tubers --------------	Kidney bean ----	1 year (Irrigated)
Rhizome --------------------	----------------	1 year (Irrigated)

Table 9. Seed rate (kg/ha/yr ±SD) and fertilizer consumption (q/ha/yr ±SD) for different crops grown at 380 to 500 m asl without integration of trees.

Season	Crop components	Crops	Seed rate	Fertilizer consumption		
				FYM	Urea	DAP
Winter	MCC-1	Wheat	64.5±5.2	21.13±1.7	1.42±0.1	0.34±0.1
		Mustard	2.0±0.3			
		Pea	25.8±2.2			
	Mono	Wheat	129.1±6.2	20.16±1.5	0.97±0.1	0.65±0.1
	MCC-2	Barley	48.88±4.7	18.69±2.0	-	-
		Lentil	9.8±1.2			
		Mustard	1.9±0.2			
	Mono	Onion	10.2±2.1	19.44±2.1	-	-
	Mono	Garlic (bulb)	242.0±10.1*	9.25±0.5	-	-
	Mono	Potato (tuber)	1497.0±25.7*	19.00±3.0	-	-
Summer	Mono	Kidney bean	70.7±4.1	25.65±3.5	-	-
	Mono	Sesame	7.7±1.5	11.30±1.0	-	-
	Mono	Barnyard millet	12.6±2.1	13.70±1.2	-	-
	MCC-3	Finger millet	4.0±1.0	13.10±1.2	-	-
		Cow pea	16.1±3.5			
		Black gram	8.1±2.7			
	MCC-4	Maize	44.4±5.0	11.30±1.0	-	-
		Green gram	3.9±1.0			
	Mono	Paddy	40.3±5.1	21.31±1.5	-	-
	Mono	Hog millet	14.0±2.5	-	-	-
Annual	Mono	Ginger (rhizome)	806.7±18.1*	21.00±1.7	-	-

Crop compositions and crop rotations were same as mentioned in Table 6, *Fresh wt. basis.

Table 10. Crop productivity (q/ha/yr ±SD) at 380 to 500 m asl in control plots.

Season	Crop components	Crops	Productivity			
			Grain	Husk	Stem	Total crop byproduct
Winter	MCC-1	Wheat	26.5±2.5	8.8±1.7	34.47±3.1	43.3
		Mustard	2.1±0.5	2.2±0.7	4.49±1.0	6.7
		Pea	2.9±0.7	0.7±0.2	2.00±0.2	2.7
	Mono	Wheat	34.0±3.1	9.5±2.0	37.64±5.7	47.2
	MCC-2	Barley	25.2±3.6	5.9±1.0	28.51±3.7	34.5
		Lentil	1.9±0.5	0.8±0.2	2.69±0.3	3.5
		Mustard	2.0±0.8	2.3±0.8	2.70±0.3	5.0
	Mono	Onion (bulb)*	-	-	159.24±8.1	-
	Mono	Garlic (bulb)*	-	-	42.21±3.5	-
	Mono	Potato (tuber)*	-	-	197.33±10.7	-
Summer	Mono	Sesame	4.6±1.1	3.9±1.0	9.88±2.1	13.8
	Mono	Barnyard millet	15.9±3.1	2.9±0.9	33.35±4.8	36.3
	MCC-3	Finger millet	6.0±1.2	1.8±0.7	13.29±2.3	15.0
		Cow pea	5.8±1.4	3.1±0.6	8.59±1.9	11.7
		Black gram	4.6±1.5	1.5±0.2	7.56±1.3	9.1
	MCC-4	Maize	14.8±2.1	4.8±1.1**	24.00±4.2	28.8
		Green gram	3.4±1.0	1.7±0.5	7.50±1.3	9.2
	Mono	Paddy	30.4±4.8	-	33.38±4.2	33.4
	Mono	Hog millet	17.2±3.0	2.8±0.6	23.07±2.5	25.9
	Mono	Kidney bean	21.1±3.5	5.3±1.7	9.62±1.1	14.9
Annual	Mono	Ginger (rhizome)	-	-	36.36±5.7	-

Crop compositions and crop rotations were same as mentioned in Table 6,
(*Fresh weight basis, ** Kernel weight).

Table 11. Comparative energy budget (Mj/ha/yr) for the different crops grown without integration of trees at 380 to 500 m asl.

Season	Crop components	Inputs					Outputs				Net return	Output/ Input ratio
		Human labour	Bullock power	FYM & Fertilizers	Seed	Total inputs	Grain	Dry fodder	Bund grass	Total outputs		
Winter	MCC-1	755.4	860.1	36199.5	1530.0	39345.0	52778.8	73676.1	261.3	126716.2	87371.2	3.2
	Wheat	670.8	827.5	34326.9	2090.8	37916.0	55073.5	65562.1	226.2	120861.8	82945.8	3.2
	MCC-2	544.3	651.8	27285.7	1003.1	29484.8	48811.7	60023.5	206.7	109041.9	79557.1	3.7
	Onion	825.7	600.7	28382.4	139.7	29948.5	62103.6	-	276.9	62380.5	32432.0	2.1
	Garlic	779.0	646.7	13505.0	943.8	15874.5	16461.9	-	288.6	16750.5	875.9	1.0
	Potato	576.3	726.1	27740.0	5838.3	34880.7	76958.7	-	265.2	77223.9	42343.2	2.2
Summer	Sesame	355.7	418.9	16488.2	204.2	17467.1	12331.8	20033.2	273.0	32638.0	15170.9	1.9
	Barnyard millet	480.6	609.3	19984.2	203.5	21277.6	25737.0	52645.1	487.5	78869.6	57592.0	3.7
	MCC-3	680.6	794.2	19135.8	476.3	21087.0	27390.6	50770.8	479.7	78641.1	57554.1	3.7
	MCC-4	861.4	453.1	16488.2	784.4	18587.2	29682.5	54184.4	249.6	84116.5	65529.2	4.5
	Paddy	844.2	765.7	31115.7	653.2	33378.7	49332.2	48402.4	214.5	97949.2	64570.5	2.9
	Hog millet	508.8	451.2	-	226.1	1186.1	27950.0	37581.1	-	65531.1	64345.0	55.2
	Kidney bean	637.4	850.4	37451.9	1201.2	40140.9	35846.2	20692.9	202.8	56741.9	16601.0	1.4
Annual	Ginger	450.2	605.3	30660.0	2258.6	33974.1	55630.8	-	468.0	56098.0	22123.8	1.6
Average*		**1073.8**	**1135.0**	**41763.6**	**1848.4**	**45820.8**	**67486.6**	**69081.7**	**478.0**	**137046.3**	**91225.5**	**3.0**

Crop compositions and crop rotations were same as mentioned in Table 6, *based on crop rotation.

Table 12. Monetary input and output (Rs/ha/yr) for different crops grown without integration of trees at 380 to 500 m asl.

Season	Crop components	Inputs					Outputs				Net return	Output/ Input ratio
		Human labour	Bullock labour	FYM & fertilizers	Seed	Total	Grain	Dry fodder	Bund grass	Total		
Winter	MCC-1	10,968	2661	3044	901	17,574	22,090	2406	67	24,563	6989	1.4
	Wheat	9542	2560	3000	1032	16,134	20,398	2358	58	22,814	6680	1.4
	MCC-2	7236	2016	1870	463	11,585	15,921	1715	53	17,689	6004	1.5
	Onion	12,851	1858	1944	1626	18,279	63,696	-	71	63,767	45,488	3.5
	Garlic	11,233	2001	925	2420	16,579	42,210	-	74	42,284	25,705	2.5
	Potato	8892	2247	1900	7485	20,524	59,199	-	68	59,267	38,743	2.9
Summer	Sesame	4501	1296	2565	154	8516	9272	-	70	9342	826	1.1
	Barnyard millet	6632	1885	1130	63	9710	7943	1668	125	9736	26	1.0
	MCC-3	8771	2457	1369	391	12,988	19,690	898	123	20,71	1021	1.6
	MCC-4	10,691	1411	1311	440	13,853	18,571	1283	64	19,918	6065	1.4
	Paddy	10,921	2369	1130	242	14,662	15,226	1669	55	16,950	2288	1.2
	Hog millet	6622	1396	-	70	8088	8626	1153	-	9779	1691	1.2
	Kidney bean	9086	2631	1396	1554	14,667	42,172	263	52	42,487	24,820	2.9
Annual	Ginger	7386	1873	2100	8067	19,426	54,540	-	120	54,660	35,234	2.8
Average*		**14,764**	**3512**	**2929**	**2460**	**23,665**	**41,355**	**1916**	**123**	**43,394**	**19,729**	**1.8**

Crop compositions and crop rotations were same as mentioned in Table 6, *based on crop rotation.

Table 13. Dominance and ecological success of tree species in three agroforestry systems at 380 to 500 m asl (n=20 number of quadrats in each system).

Plant species	Relative Frequency (%)			Relative Density (%)			Relative Dominance (%)			Important Value Index (IVI)		
	AS	AH	AHS	AS	AH	AHS	AS	AH	AHS	AS	AH	AHS
Fuelwood, fodder & timber trees												
Albizia lebbek	-	-	3.9	-	-	4.3	-	-	4.3	-	-	12.5
Bauhinia variegata	5.2	-	-	6.9	-	-	6.0	-	-	18.1	-	-
Boehmeria rugulosa	8.7	-	4.5	9.5	-	4.8	7.6	-	3.6	25.8	-	12.9
Celtis australis	0.7	-	-	0.6	-	-	0.8	-	-	2.1	-	-
Dalbergia sissoo	-	-	12.5	-	-	7.2	-	-	17.8	-	-	37.5
Ficus auriculata	8.2	-	2.1	7.4	-	2.4	5.7	-	1.7	21.2	-	6.2
F. cunia	4.4	-	3.9	2.1	-	3.6	3.2	-	3.4	9.6	-	10.7
F. hispida	4.4	-	2.1	3.1	-	1.9	2.7	-	2.4	10.2	-	6.4
F. palmata	6.1	-	-	9.8	-	-	3.9	-	-	19.8	-	-
Grewia optiva	19.4	-	10.3	21.3	-	9.6	23.2	-	9.8	63.9	-	29.6
Leuceaena leucocephala	6.5	-	-	4.0	-	-	1.0	-	-	11.6	-	-
Mallotus philippensis	10.5	-	-	15.1	-	-	12.4	-	-	38.1	-	-
Melia azedarach	13.4	-	6.5	8.2	-	9.6	11.3	-	12.4	33.0	-	28.5
Morus alba	-	-	6.0	-	-	7.2	-	-	5.6	-	-	18.8
Ougeinia oojeinensis	4.4	-	-	5.3	-	-	6.2	-	-	15.9	-	-
Toona ciliata	8.1	-	-	6.7	-	-	15.8	-	-	30.7	-	-
Fruit trees												-
Artocarpus heterophyllus	-	6.8	-	-	7.1	-	-	8.0	-	-	21.9	-
Carica papaya	-	20.5	-	-	18.1	-	-	16.2	-	-	54.8	-
Citrus aurantifolia	-	26.7	8.1	-	28.2	7.2	-	28.8	6.1	-	83.7	21.4
C. limonia	-	-	5.0	-	-	4.8	-	-	4.1	-	-	13.8
C. maxima	-	-	3.6	-	-	4.2	-	-	3.6	-	-	11.4
Mangifera indica	-	24.5	12.5	-	23.8	9.6	-	31.1	10.5	-	79.3	32.6
Musa paradisica	-	6.5	7.3	-	4.1	9.6	-	3.4	6.7	-	14.0	23.6
Prunus persica	-	-	3.6	-	-	4.8	-	-	2.7	-	-	11.0
Psidium guajava	-	15.0	8.1	-	18.8	9.6	-	12.5	5.3	-	46.2	23.0

AS- Agrisilviculture, AH- Agrihorticulture and AHS- Agrihortisilviculture agroforestry system.

Table 14. Tree productivity in different agroforestry systems at 380 to 500 m asl.

Tree Species	Uses	Tree productivity (kg/tree/yr ±SD)	Agroforestry Systems (kg/ha/yr ±SD)		
			AS	AH	AHS
Albizia lebbek	Fodder	15.3±3.1	-	-	159.1±32.2
	Fuelwood	4.9±1.0	-	-	51.2±10.3
	Timber volume (m^3)	0.4±0.1	-	-	3.8±1.1
Bauhinia variegata	Fodder	11.1±2.0	114.2±20.6	-	-
	Fuelwood	4.0±0.9	41.0±9.7	-	-
Boehmeria rugulosa	Fodder	24.1±3.7	342.1±53.6	-	278.0±43.5
	Fuelwood	11.0±2.1	156.4±30.3	-	127.1±24.6
	Timber volume (m^3)	0.1±0.0	1.4±0.4	-	1.1±0.3
Celtis australis	Fodder	10.1±2.1	8.3±1.8	-	-
	Fuelwood	3.2±1.0	2.6±0.8	-	-
D. sissoo	Timber volume (m^3)	1.0±0.4	-	-	17.8±6.9
Ficus auriculata	Fodder	11.4±2.0	125.6±22.7	-	65.7±11.8
	Fuelwood	4.9±1.0	54.2±11.6	-	28.3±6.1
F. cunia	Fodder	10.3±2.0	48.2±8.3	-	88.8±17.3
	Fuelwood	5.1±1.1	23.8±5.3	-	43.8±9.8
F. hispida	Fodder	12.3±2.1	38.2±6.5	-	56.8±9.7
	Fuelwood	3.4±0.9	10.6±2.9	-	15.7±4.3
F. palmata	Fodder	5.1±1.1	75.2±13.1	-	-
	Fuelwood	1.0±0.1	14.7±1.6	-	-
Grewia optiva	Fodder	15.0±3.0	478.3±96.6	-	346.0±69.9
	Fuelwood	6.2±1.5	200.0±50.8	-	144.2±36.5
	Fibre	.0.4±0.1	13.1±3.8	-	9.5±2.7
Leuceaena leucocephala	Fodder	2.0±0.1	12.0±0.7	-	-
	Fuelwood	1.3±0.1	7.9±0.6	-	-
Mallotus philippensis	Fodder	8.8±1.7	198.3±38.6	-	-
	Fuelwood	5.3±1.2	119.9±27.3	-	-
Melia azedarach	Fodder	17.5±3.7	216.1±46.1	-	404.4±86.2
	Fuelwood	9.9±2.5	121.7±30.9	-	227.7±57.9
Morus alba	Fodder	13.9±3.0	-	-	241.3±51.9
	Fuelwood	5.6±1.7	-	-	96.9±30.1

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Ougeinia oojeinensis	Fodder	13.5±2.7	108.0±22.2	-	-
	Fuelwood	6.9±1.5	55.4±12.6	-	-
	Timber volume (m^3)	0.8±0.3	6.5±2.9	-	-
Toona ciliata	Timber volume (m^3)	0.8±0.4	8.3±4.0	-	-
Artocarpus heterophyllus	Fruit	66.0±10.5	-	532.0±84.6	-
Carica papaya	Fruit	16.7±4.1	-	407.7±86.2	-
Citrus aurantifolia	Fruit	12.5±3.2	-	403.8±103.7	216.8±50.7
C. limonia	Fruit	15.0±3.7	-	-	172.5±43.2
C. maxima	Fruit	28.5±6.1	-	-	289.0±62.5
Mangifera indica	Fruit	20.6±5.0	-	559.7±137.7	475.2±116.9
Musa paradisica	Fruit	10.0±3.1	-	46.7±14.6	230.7±72.2
P. persica	Fruit	13.5±4.0	-	-	155.4±47.0
Psidium guajava	Fruit	17.3±5.8	-	372.1±124.7	399.8±130.0

Table 14.1. Total productivity (q/ha/yr ±SD) of different agroforestry systems at 380 to 500 m asl.

Uses	Control	Agroforestry Systems		
		AS	AH	AHS
Tree fodder	-	17.6±3.3	-	16.4±3.3
Fuelwood	-	8.1±1.8	-	7.4±1.8
Timber volume (m^3)	-	16.2±7.4	-	22.8±8.4
Fibre	-	0.1±0.0	-	0.1±0.0
Fruit	-	-	23.2±5.5	19.4±5.2
Bund grass	1.2±0.2	1.3±0.2	1.3±0.3	1.4±0.2

Table 15. Total labour input (hrs/ha/yr) for different crops grown at 380 to 500 m asl in agrisilvicultural agroforestry system.

Season	Crop components	Human labour				Bullock labour
		Man	Woman	Child	Total	
Winter	MCC-1	416.2	1172.2	-	1588.4	132.1
	Wheat	501.9	797.1	70.0	1369.0	126.7
	MCC-2	99.8	1028.3	39.9	1168.1	99.8
Summer	Sesame	64.3	678.6	100.1	842.9	64.3
	Barnyard millet	339.2	711.4	136.4	1187.0	93.6
	MCC-3	290.8	956.0	372.1	1618.8	121.9
	MCC-4	482.8	804.0	450.3	1737.1	70.0
	Paddy	286.4	972.1	662.9	1921.5	117.5
	Hog millet	227.4	476.3	317.3	1020.9	68.7

Bund area per ha of agrisilvicultural agroforestry system was 0.032 ha; Bullock = 1 Pair

MCC= Mixed Crop Composition; MCC-1= Wheat + mustard + pea; MCC-2= Barley + lentil + mustard; MCC-3= Finger millet + cowpea + black gram, and MCC-4= Maize + green gram.

Crop rotation

MCC-1------------Hog millet------	Paddy------------------	1 Year (Irrigated
Wheat-----------------------------	MCC-4------------------	1 year (Irrigated)
MCC-2-----------------------------	Sesame-----------------	1 Year (Rainfed)
MCC-3-----------------------------	Fallow------------------	1 Year (Rainfed)
Barnyard millet-------------------	Fallow------------------	1 Year (Rainfed)

Table 16. Seed rate (kg/ha/yr ± SD) and fertilizer consumption (q/ha/yr ± SD) for different crops grown in agrisilvicultural agroforestry system at 380 to 500 m asl.

Season	Crop components	Crops	Seed rate	Fertilizer consumption		
				FYM	Urea	DAP
Winter	MCC-1	Wheat	60.0±4.2	19.7±2.7	1.3±0.1	0.3±0.1
		Mustard	1.9±0.2			
		Pea	24.0±3.8			
	Mono	Wheat	120.1±6.3	18.8±2.1	0.9±0.1	0.6±0.1
	MCC-2	Barley	45.5±4.4	17.4±2.1	-	-
		Lentil	9.0±2.1			
		Mustard	1.7±0.5			
Summer	Mono	Sesame	7.1±1.7	10.5±1.0	-	-
	Mono	Barnyard millet	11.7±2.0	12.9±1.5	-	-
	MCC-3	Finger millet	3.7±0.8	12.2±1.7	-	-
		Cow pea	15.0±2.7			
		Black gram	7.5±1.8			
	MCC-4	Maize	41.3±3.1	10.5±1.1	-	-
		Green gram	3.6±0.8			
	Mono	Paddy	37.5±3.4	19.8±2.8	-	-
	Mono	Hog millet	13.0±1.7	-	-	-

Crop compositions and crop rotations were same as mentioned in Table 13.

Table 17. Crop productivity (q/ha/yr ±SD) in agrisilvicultural agroforestry system at 380 to 500 m asl.

Season	Crop components	Crops	Productivity			
			Grain	Husk	Stem	Total crop byproduct
Winter	MCC-1	Wheat	23.9±4.2	8.0±2.7	31.0±5.3	39.02
		Mustard	1.9±0.6	1.9±1.1	4.0±1.0	5.97
		Pea	2.6±0.8	0.6±0.2	1.8±0.8	2.40
	Mono	Wheat	30.6±6.1	8.6±2.8	34.0±5.6	42.58
	MCC-2	Barley	22.7±4.0	5.1±2.8	25.7±5.0	30.73
		Lentil	1.7±0.7	0.7±0.2	2.4±0.9	3.14
		Mustard	1.8±0.7	2.1±1.3	2.4±1.0	4.52
Summer	Mono	Sesame	4.2±1.3	3.5±1.8	8.9±1.5	12.44
	Mono	Barnyard millet	11.5±2.1	1.8±0.6	30.0±4.7	31.80
	MCC-3	Finger millet	5.4±1.1	1.6±0.6	12.0±3.1	13.56
		Cow pea	5.2±1.0	2.8±0.9	7.7±1.7	10.56
		Black gram	4.1±1.0	1.4±0.7	6.8±1.7	8.20
	MCC-4	Maize	13.3±2.5	4.4±2.1	20.6±3.7	24.98
		Green gram	3.0±1.1	1.5±0.8	6.7±1.6	8.25
	Mono	Paddy	27.4±5.3	-	30.1±4.3	30.06
	Mono	Hog millet	15.5±3.7	2.6±1.3	21.0±3.1	23.56

Crop compositions and crop rotations were same as mentioned in Table 13.

Table 18. Comparative energy budget (Mj/ha/yr) for different crops grown in agrisilvicultural agroforestry system at 380 to 500 m asl.

Season	Crop components	Inputs					Outputs						Net return	Output/ Input ratio
		Human labour	Bullock power	FYM & Fertilizers	Seed	Total inputs	Grain	Dry fodder	Bund grass	Tree fodder	Fuelwood	Total outputs		
Winter	MCC-1	754.2	800.3	33677.7	1423.2	36655.4	47451.4	65866.1	237.9	3894.1	7904.2	125353.7	88698.3	3.4
	Wheat	673.7	767.8	31934.6	1945.1	35321.3	49601.2	59172.7	210.6	3894.1	7904.2	120782.8	85461.5	3.4
	MCC-2	553.8	604.7	25375.5	930.0	27464.0	43961.3	53373.9	230.1	3894.1	7904.2	109363.6	81899.6	4.0
Summer	Sesame	396.2	389.6	15334.0	187.1	16306.9	11106.3	17296.0	288.6	3517.7	8502.1	40710.7	24403.8	2.5
	Barnyard millet	562.6	567.4	18585.3	189.2	19904.5	18610.0	46108.1	538.2	7411.7	16406.4	89074.4	69169.9	4.5
	MCC-3	748.6	738.8	17796.2	443.1	19726.6	24668.9	45735.8	518.7	7411.7	16406.4	94741.4	75014.8	4.8
	MCC-4	866.7	424.3	15339.1	729.8	17359.8	26733.0	47689.3	308.1	3517.7	8502.1	86750.2	69390.4	5.0
	Paddy	846.5	712.3	28937.6	607.7	31104.1	44430.3	43593.0	280.8	3517.7	8502.1	100323.9	69219.8	3.2
	Hog millet	473.2	416.5	-	210.3	1099.9	25172.5	34144.2	-	-	-	59316.7	58216.8	53.9
Average*		**1175.1**	**1084.1**	**37396.0**	**1333.1**	**40988.3**	**58346.9**	**82595.8**	**522.6**	**7411.7**	**16406.3**	**165283.4**	**124295.1**	**4.0**

Crop compositions and crop rotations were same as mentioned in Table 13, *based on crop rotation.

Table 19. Monetary input and output (Rs/ha/yr) for different crops grown in agrisilvicultural agroforestry system at 380 to 500 m asl.

Season	Crop components	Inputs					Outputs						Net return	Output/ Input ratio
		Human labour	Bullock power	FYM & Fertilizers	Seed	Total inputs	Grain	Dry fodder	Bund grass	Tree fodder	Fuelwood	Total outputs		
Winter	MCC-1	10,969	2476	2790	838	17,073	19,858	2197	61	2781	859	25,756	8683	1.5
	Wheat	9636	2376	2791	960	15,763	18,371	2128	54	2781	859	24,193	8430	1.5
	MCC-2	7450	1871	1338	428	11,487	14,338	1798	59	2781	859	19,835	8348	1.7
Summer	Sesame	5178	1205	1050	143	7576	8351	-	74	2044	432	10,901	3325	1.4
	Barnyard millet	7926	1755	1273	58	11,012	5744	1502	138	4825	1291	13,500	2488	1.2
	MCC-3	9914	2286	1220	364	13,784	17,732	809	133	4825	1291	24,790	11,006	1.8
	MCC-4	10,937	1313	1051	409	13,710	16,726	1106	79	2044	432	20,387	6670	1.5
	Paddy	11,068	2204	1982	225	15,479	13,713	1503	72	2044	432	17,764	2285	1.1
	Hog millet	6157	1289	-	65	7511	7769	1049	-	-	-	8,818	1307	1.2
Average*		**15,847**	**3355**	**2779**	**698**	**22,679**	**24,521**	**2418**	**134**	**4825**	**1291**	**33,189**	**10,510**	**1.5**

Crop compositions and crop rotations were same as mentioned in Table 13, *based on crop rotation.

Table 20. Total labour input (hrs/ ha/yr) for different crops grown in agrihorticultural agroforestry system at 380 to 500 m asl.

Season	Crop components	Human labour				Bullock labour
		Man	Woman	Child	Total	
Winter	Wheat	488.0	822.6	68.0	1378.6	123.4
	MCC-2	97.0	1174.3	38.8	1310.0	97.0
Summer	Barnyard millet	280.3	700.7	132.6	1113.5	90.9
	MCC-3	319.0	902.0	361.5	1582.5	118.5
	Paddy	278.3	906.7	644.1	1829.1	114.2

Bund area per ha of agrihorticultural agroforestry system was 0.033 ha; Bullock = 1 Pair

MCC = Mixed Crop Composition; MCC-2 = Barley + lentil + mustard and MCC-3 = Finger millet + cow pea + black gram.

Crop rotation

Wheat ------------------ Paddy------------------ 1 Year (Irrigated)

MCC-2------------------ Fallow------------------ 1 Year (Rainfed)

Barnyard millet------- Fallow------------------ 1 Year (Rainfed)

MCC-3------------------ Fallow------------------ 1 Year (Rainfed)

Table 21. Seed rate input (kg/ha/yr ±SD) and fertilizer consumption (q/ha/yr ±SD) for different crops grown in agrihorticultural agroforestry system at 380 to 500 m asl.

Season	Crop components	Crops	Seed rate	Fertilizer consumption		
				FYM	Urea	DAP
Winter	Mono	Wheat	116.7±9.7	20.0±2.0	0.9±0.1	0.6±0.1
	MCC-2	Barley	44.2±4.2	20.3±2.1	-	-
		Lentil	8.8±1.7			
		Mustard	1.8±0.5			
Summer	Mono	Barnyard millet	11.4±1.7	15.8±1.6	-	-
	MCC-3	Finger millet	3.6±0.8	15.3±1.5	-	-
		Cow pea	14.6±2.1			
		Black gram	7.3±1.2			
	Mono	Paddy	36.4±4.0	20.9±2.2	-	-

Crop compositions and crop rotations were same as mentioned in Table 18.

Table 22. Crop productivity (q/ha/yr ±SD) in agrihorticultural agroforestry system at 380 to 500 m asl.

Season	Crop components	Crops	Productivity			
			Grain	Husk	Stem	Total crop byproduct
Winter	Mono	Wheat	28.7±5.7	7.6±2.1	31.0±6.1	38.6
	MCC-2	Barley	20.8±4.1	4.1±1.7	23.8±4.3	27.9
		Lentil	1.2±0.1	0.6±0.2	2.1±1.6	2.7
		Mustard	1.4±0.2	1.6±0.8	2.0±1.5	3.6
Summer	Mono	Barnyard millet	10.5±2.2	1.6±0.8	28.1±5.7	29.7
	MCC-3	Finger millet	4.4±1.1	1.2±0.7	11.0±3.2	12.2
		Cow pea	4.2±1.1	1.8±0.8	6.8±2.1	8.6
		Black gram	3.1±0.5	1.2±0.6	5.8±2.0	7.0
	Mono	Paddy	26.5±4.5	-	28.2±5.6	28.2

Crop compositions and crop rotations were same as mentioned in Table 18.

Table 23. Comparative energy budget (Mj/ha/yr) for different crops grown in agrihorticultural agroforestry system at 380 to 500 m asl.

Season	Crop components	Inputs					Outputs					Net return	Output/ Input ratio
		Human labour	Bullock power	FYM & Fertilizers	Seed	Total inputs	Grain	Dry fodder	Bund grass	Fruit	Total outputs		
Winter	Wheat	672.3	748.1	33588.0	1890.0	36898.4	46546.5	53708.1	280.8	12273.3	112808.7	75910.3	3.0
	MCC-2	606.5	587.7	29674.3	906.6	31775.1	39112.9	47611.9	538.2	34644.5	121907.6	90132.5	3.8
Summer	Barnyard millet	541.8	550.7	23073.8	184.0	24350.4	17059.4	43090.4	550.0	34644.5	95344.3	70993.9	3.9
	MCC-3	733.1	718.0	22306.8	430.6	24188.4	19741.3	39428.6	526.5	34644.5	94341.0	70152.6	3.9
	Paddy	805.3	692.1	30580.1	590.5	32668.1	42976.3	40855.8	257.4	22371.2	106460.7	73792.6	3.3
Average*		**839.8**	**824.2**	**34805.8**	**1000.4**	**37470.1**	**41359.1**	**56173.7**	**538.2**	**34644.5**	**132715.6**	**95245.5**	**3.5**

Crop compositions and crop rotations were same as mentioned in Table 18, *based on crop rotation.

Table 24. Monetary input and output (Rs/ha/yr) for different crops grown in agrihorticultural agroforestry system of Kumaun Himalaya at 380 to 500 m asl.

Season	Crop components	Inputs					Outputs					Net return	Output/ Input ratio
		Human labour	Bullock power	FYM & Fertilizers	Seed	Total inputs	Grain	Dry fodder	Bund grass	Fruit	Total outputs		
Winter	Wheat	9666	2315	2888	933	15,802	17,239	1932	72	6557	25,800	9998	1.6
	MCC-2	8332	1818	2032	419	12,601	12,192	1713	138	19,948	33,991	21,390	2.7
Summer	Barnyard millet	7328	1704	1580	57	10,669	5265	1407	141	19,948	26,761	16,092	2.5
	MCC-3	9784	2221	1528	353	13,886	13,999	702	135	19,948	34,784	20,898	2.5
	Paddy	10,553	2648	2094	219	15,514	13,264	1409	66	13,391	28,130	12,616	1.8
Average*		**11,416**	**2677**	**2530**	**495**	**17,118**	**15,490**	**1791**	**138**	**19,948**	**37,367**	**20,249**	**2.2**

Crop compositions and crop rotations were same as mentioned in Table 18, *based on crop rotation.

Table 25. Total labour input (hrs/ha/yr) for different crops grown in agrihortisilvicultural agroforestry system at 380 to 500 m asl

Season	Crop components	Crops	Human labour				Bullock labour
			Man	Woman	Child	Total	
Winter	MCC-2	MCC-2	92.3	1117.6	36.9	1246.8	92.3
	Bulb & Tubers (Mono)	Onion	291.8	1393.0	400.6	2085.3	85.2
		Garlic	301.8	1097.3	467.5	1866.6	91.8
		Potato	476.9	739.9	150.3	1367.1	103.0
	Spices (Mono)	Fenugreek	-	1405.7	-	1405.7	-
		Coriander	-	1339.3	-	1339.3	-
	Leafy vegetables (Mono)	Cabbage	-	1357.0	-	1357.0	-
		Mustard leaf	-	1396.9	-	1396.9	-
		Spinach	-	1387.9	-	1387.9	-
Summer	MCC-3	MCC-3	268.8	855.9	343.9	1468.6	112.7
	Mono	Barnyard millet	266.7	605.5	126.1	998.4	86.5
	Summer vegetables (Mono)	Bitter gourd	-	728.5	-	728.5	-
		Bottle gourd	-	745.7	-	745.7	-
		Brinjal	-	1330.1	-	1330.1	-
		Chilli	-	1470.1	-	1470.1	-
		Cucumber	-	723.1	-	723.1	-
		French bean	-	1099.7	-	1099.7	-
		Ladies finger	-	1111.2	-	1111.2	-
		Pumpkin	-	721.6	-	721.6	-
		Radish	-	978.7	-	978.7	-
		Snake gourd	-	677.1	-	677.1	-
		Tomato	-	1442.3	-	1442.3	-
Annually	Rhizome (Mono)	Ginger	380.9	878.2	127.0	1386.1	85.9
		Turmeric	302.1	803.7	108.0	1213.8	94.7
		Elephant ear	283.0	766.4	89.2	1138.6	89.2

Bund area per ha of agrihortisilvicultural agroforestry system was 0.032 ha; Bullock =1 Pair

MCC= Mixed Crop Composition; MCC-2=Barley + Lentil + Mustard and MCC-3= Finger millet + Cow pea + Black gram.

Crop rotation

MCC-2----------------------	Summer vegetables ----------------	1 year
MCC-3----------------------	Leafy vegetables/spices------------	1 year
Barnyard millet -----------	Bulb and tuber --------------------	1 year
Rhizome ------------------	---	1 year

Table 26. Seed rate (kg/ha/yr ±SD) and fertilizer consumption (q/ha/yr ±SD) in agrihortisilvicultural agroforestry system at 380 to 500 m asl.

Season	Crop components	Crops	Seed rate	FYM
Winter	MCC-2	Barley	48.0±4.3	22.1±2.5
		Lentil	8.4±2.2	
		Mustard	1.7±0.5	
	Bulb & tubers (Mono)	Onion	8.7±2.1	20.6±2.6
		Garlic	208.12±10.7*	20.5±2.4
		Potato	1287.4±25.5*	20.3±2.0
	Spices (Mono)	Fenugreek	22.7±3.5	23.6±2.7
		Coriander	33.3±3.7	23.0±3.0
	Leafy vegetables (Mono)	Cabbage	0.6±0.0	24.0±3.5
		Mustard leaf	14.8±2.1	24.5±4.0
		Spinach	24.0±3.5	24.4±4.0
Summer	MCC-3	Finger millet	3.4±1.0	12.3±1.7
		Cow pea	13.9±2.5	
		Black gram	6.9±1.6	
	Mono	Barnyard millet	11.8±2.3	12.8±1.7
	Summer vegetables (Mono)	Bitter gourd	6.5±0.8	11.6±1.5
		Bottle gourd	5.0±0.8	11.5±1.5
		Brinjal	0.6±0.1	12.2±1.5
		Chilli	0.9±0.1	19.7±2.5
		Cucumber	3.0±0.6	11.2±1.3
		French bean	35.7±5.7	19.6±3.0
		Ladies finger	15.0±2.7	19.2±3.1
		Pumpkin	5.5±1.0	11.0±2.0
		Radish	10.0±1.1	20.1±3.5
		Snake gourd	4.3±0.9	10.1±1.7
		Tomato	0.6±0.1	21.7±3.2
Annual	Rhizome (Mono)	Ginger	693.7±15.2*	23.0±4.6
		Turmeric	825.0±20.5*	21.8±3.7
		Elephant ear	1028.0±33.2*	21.2±3.5

Crop compositions and crop rotations were same as mentioned in Table 23, *Fresh weight basis

Table 27. Crop productivity (q/ha/yr ±SD) of major crops in agrihortisilvicultural agroforestry system at 380 to 500 m asl.

Season	Crop components	Crops	Productivity			
			Grain	Husk	Stem	Total crop byproduct
Winter	MCC-2	Barley	19.2±3.4	3.8±1.7	21.8±4.2	25.6
		Lentil	1.3±0.8	0.4±0.1	2.0±0.1	2.4
		Mustard	1.4±0.9	1.6±0.6	1.8±0.6	3.4
Summer	MCC-3	Finger millet	4.0±1.5	1.0±0.5	8.3±3.1	9.3
		Cow pea	4.0±1.6	2.0±1.0	5.0±2.7	7.1
		Black gram	3.1±1.4	1.1±0.2	4.1±2.5	5.2
	Mono	Barnyard millet	7.9±2.1	1.4±0.5	19.3±4.0	20.7

Crop compositions and crop rotations were same as mentioned in Table 23.

Table 27.1. Productivity (q/ha/yr ±SD) of major vegetables in agrihortisilvicultural agroforestry system at 380 to 500 m asl.

Season	Crop components	Vegetables	Productivity
Winter	Bulb & tubers (Mono)	Onion	115.0±6.5
		Garlic	31.0±2.1
		Potato	130.0±6.7
	Spices (Mono)	Fenugreek	5.7±0.5*
		Coriander	11.2±1.5*
	Leafy vegetables (Mono)	Cabbage	151.0±11.7
		Mustard leaf	111.1±12.2
		Spinach	81.4±7.3
Summer	Summer Vegetables (Mono)	Bitter gourd	46.4±2.1
		Bottle gourd	85.2±6.0
		Brinjal	82.1±6.5
		Chilli	24.1±1.3*
		Cucumber	47.3±1.5
		French bean	41.1±1.4
		Ladies finger	50.5±3.8
		Pumpkin	98.7±6.2
		Radish	103.4±9.5
		Snake gourd	42.5±1.1
		Tomato	91.0±4.2
Annually	Rhizome (Mono)	Ginger	40.1±3.6*
		Turmeric	61.2±4.1*
		Elephant ear	134.2±8.9

Crop compositions and crop rotations were same as mentioned in Table 23, *Dry wt. Basis.

Table 28. Comparative energy budget (Mj/ha/yr) for different crops grown in agrihortisilvicultural agroforestry system at 380 to 500 m asl.

Season	Crop components	Inputs					Outputs							Net return	Output/ Input ratio
		Human labour	Bullock labour	FYM	Seed	Total inputs	Grain/ Vegetables	Dry fodder	Bund grass	Tree fodder	Fuelwood	Fruit	Total outputs		
Winter	MCC-2	576.9	559.1	32282.4	961.6	34380.0	3661.6	43679.9	261.3	3232.7	6517.1	19526.8	109839.5	75459.5	3.2
	Onion	857.7	516.6	30156.3	120.2	31650.7	44850.0	-	265.2	3232.7	6517.1	19526.8	74391.9	42840.4	2.3
	Garlic	765.7	556.2	29917.7	811.7	32051.3	12090.0	-	280.8	3232.7	6517.1	19526.8	41647.5	9596.2	1.3
	Potato	604.7	624.4	29604.6	5020.9	35854.7	50700.0	-	249.6	3232.7	6517.1	19526.8	80226.3	44371.7	2.2
	Fenugreek	565.5	-	34511.5	311.6	35388.5	7878.7	-	237.9	3232.7	6517.1	19526.8	37393.4	2004.9	1.0
	Coriander	536.9	-	33563.3	458.3	34558.5	15413.7	-	292.5	3232.7	6517.1	19526.8	44983.0	10424.5	1.3
	Cabbage	525.0	-	35057.8	8.2	35591.1	42280.0	-	273.0	3232.7	6517.1	19526.8	71829.7	36238.7	2.0
	Mustard leaf	550.2	-	35811.8	341.4	36703.5	31108.0	-	214.5	3232.7	6517.1	19526.8	60599.2	23895.8	1.6
	Spinach	547.0	-	35616.7	330.0	36493.7	22803.2	-	319.8	3232.7	6517.1	19526.8	52399.7	15906.0	1.4
Summer	MCC-3	675.2	683.1	17970.1	409.5	19737.9	18679.5	30539.6	279.9	3656.5	7960.4	9409.4	70525.3	50787.43	3.6
	Barnyard millet	475.7	524.5	18701.9	191.2	19893.3	12844.2	30022.1	304.2	3656.5	7960.4	9409.4	64196.8	44303.55	3.2
	Bitter gourd	288.0	-	16918.8	89.4	17296.1	11148.0	-	261.3	3656.5	7960.4	9409.4	32435.6	15139.5	1.9
	Bottle gourd	295.4	-	16844.2	68.7	17208.4	20455.2	-	296.4	3656.5	7960.4	9409.4	41777.9	24569.5	2.4
	Brinjal	507.4	-	26595.4	8.3	27111.1	19706.4	-	206.7	3656.5	7960.4	9409.4	40939.4	13828.4	1.5
	Chilli	562.5	-	28744.3	12.4	29319.1	33137.5	-	234.0	3656.5	7960.4	9409.4	54397.8	25078.7	1.8
	Cucumber	285.3	-	16403.1	41.2	16729.7	11352.0	-	210.6	3656.5	7960.4	9409.4	32588.9	15859.3	1.9
	French bean	428.8	-	28657.0	607.1	29692.8	69870.0	-	265.2	3656.5	7960.4	9409.4	91161.5	61468.7	3.1
	Ladies finger	434.5	-	27989.0	206.2	28629.7	12122.0	-	288.6	3656.5	7960.4	9409.4	33436.9	4807.2	1.2
	Pumpkin	283.6	-	16115.8	75.6	16475.0	23690.4	-	312.0	3656.5	7960.4	9409.4	45028.7	28553.7	2.7
	Radish	386.8	-	29372.3	230.7	29989.1	24825.6	-	327.6	3656.5	7960.4	9409.4	46179.5	16190.4	1.5
	Sponge gourd	266.9	-	14001.5	59.1	15427.5	10200.0	-	210.4	3656.5	7960.4	9409.4	31444.7	16317.2	2.1
	Tomato	549.0	-	31646.8	8.3	32204.1	24848.0	-	183.8	3656.5	7960.4	9409.4	43030.1	10826.0	1.3
Annual	Ginger	600.6	520.5	33631.3	1942.4	36694.9	61368.3	-	526.5	6889.3	14477.5	28936.3	112197.8	75503.0	3.0
	Turmeric	535.6	573.9	31865.4	2310.0	35284.9	93666.6	-	546.0	6889.3	14477.5	28936.3	144515.7	109230.8	4.1
	Elephant ear	499.5	540.7	30900.3	2878.4	34818.9	37576.0	-	507.0	6889.3	14477.5	28936.3	88389.1	53570.2	2.5
Average*		**987.6**	**577.9**	**472747.7**	**1585.3**	**50398.6**	**45662.9**	**26060.4**	**539.4**	**6889.3**	**14477.5**	**28936.3**	**122565.9**	**72167.3**	**2.4**

Crop compositions and crop rotations were same as mentioned in Table 23, *based on crop rotation.

Table 29. Monetary input and output (Rs/ha/yr) for different crops grown in agrihortisilvicultural agroforestry system at 380 to 500 m asl.

Season	Crop components	Inputs					Outputs							Net return	Output / Input ratio
		Human labour	Bullock labour	FYM	Seed	Total inputs	Grain/ Vegetables	Dry fodder	Bund grass	Tree fodder	Fuelwood	Fruit	Total outputs		
Winter	MCC-2	7930	1730	2211	477	12,348	12,018	1481	67	2309	662	9012	25,549	13,201	2.1
	Onion	12,761	1598	2065	1398	17,822	46,000	-	68	2309	662	9012	58,051	40,229	3.3
	Garlic	11,252	1721	2049	2081	17,103	31,000	-	72	2309	662	9012	43,055	25,952	2.5
	Potato	9360	1932	2028	6437	19,757	39,000	-	64	2309	662	9012	51,047	31,290	2.6
	Fenugreek	8785	-	2364	566	11,715	11,460	-	61	2309	662	9012	23,504	11,789	2.0
	Coriander	8371	-	2299	667	11,337	22,420	-	75	2309	662	9012	34,478	23,141	3.0
	Cabbage	8481	-	2401	192	11,074	45,300	-	70	2309	662	9012	57,343	46,279	5.2
	Mustard leaf	8731	-	2453	222	11,406	22,220	-	55	2309	662	9012	34,258	22,852	3.0
	Spinach	8675	-	2439	1920	13,034	16,288	-	82	2309	662	9012	28,353	15,319	2.2
Summer	MCC-3	8991	2113	1231	336	12,671	13,483	533	71	2048	404	5529	22,158	9487	1.7
	Barnyard millet	6592	1623	1281	59	9555	3964	967	78	2048	404	5529	12,990	3435	1.4
	Bitter gourd	4553	-	1159	455	6167	23,225	-	67	2048	404	5529	31,273	25,106	5.1
	Bottle gourd	4660	-	1154	400	6214	25,569	-	76	2048	404	5529	33,626	27,412	5.4
	Brinjal	8313	-	1822	210	10,345	24,633	-	53	2048	404	5529	32,667	23,320	3.2
	Chilli	9188	-	1969	135	11,292	36,150	-	60	2048	404	5529	44,191	32,899	3.9
	Cucumber	4520	-	1123	300	5943	18,920	-	54	2048	404	5529	26,955	21,012	4.5
	French bean	6873	-	1963	893	9729	16,440	-	68	2048	404	5529	24,489	14,760	2.5
	Ladies finger	6945	-	1917	675	9537	20,202	-	74	2048	404	5529	28,257	18,720	3.0
	Pumpkin	4510	-	1104	440	6054	29,613	-	80	2048	404	5529	37,674	31,620	6.2
	Radish	6117	-	2012	200	8329	20,688	-	84	2048	404	5529	28,753	20,424	3.4
	Snake gourd	4232	-	1014	344	5590	21,250	-	56	2048	404	5529	29,287	23,697	5.2
	Tomato	9015	-	2168	222	11,405	45,500	-	42	2048	404	5529	53,523	42,118	4.7
Annual	Ginger	9298	1610	2303	6937	20,148	60,165	-	135	4357	1066	14,541	80,264	60,116	4.0
	Turmeric	8071	1776	2182	5775	17,804	48,976	-	140	4357	1066	14,541	69,080	51,276	3.9
	Elephant ear	7600	1673	2116	3084	14,473	26,840	-	130	4357	1066	14,541	46,934	32,461	3.2
Average*		**14,459**	**2225**	**3236**	**2636**	**22,556**	**40,663**	**768**	**138**	**4357**	**1066**	**14,541**	**61,533**	**38,977**	**2.7**

Crop compositions and crop rotations were same as mentioned in Table 23, *based on crop rotation.

Table 30. Comparative energy input and output (Mj/ha/yr) patterns for different crops grown in control and agroforestry systems at 380-500 m asl.

Parameters	Energy			
	Control	AS	AH	AHS
Inputs				
Human labour	1073.8 (2.3%)	1175.08 (2.87%)	839.7 (2.2%)	987.6 (2.0%)
Bullock labour	1135.0 (2.5%)	1084.15 (2.64%)	824.2 (2.2%)	577.9 (1.1%)
FYM & Fertilizers	41763.6 (91.1%)	37395.99 (91.23%)	34805.7 (92.9%)	472747.7 (93.7%)
Seed	1848.4 (4.0%)	1333.08 (3.26%)	1000.4 (2.7%)	1585.3 (3.1%)
Total inputs	**45820.8**	**40988.30**	**37470.1**	**50398.6**
Outputs				
Grain/vegetables yield	67486.6 (49.2%)	58346.95 (35.30%)	41359.1 (31.2%)	45662.9 (37.2%)
Crop residue	69081.7 (50.4%)	82595.81 (49.97%)	56173.7 (42.3%)	26060.4 (21.3%)
Fodder from weed & grasses of the bunds	478.0 (0.35%)	522.60 (0.32%)	538.2 (0.4%)	539.4 (0.4%)
Fodder from agroforestry trees	-	7411.74 (4.48%)	-	6889.3 (5.6%)
Fuelwood from agroforestry trees	-	16406.35 (9.93%)	-	14477.5 (11.8%)
Fruit from agroforestry trees	-	-	34644.5 (26.1%)	28936.3 (23.6%)
Total outputs	**137046.3**	**165283.4**	**132715.6**	**122565.9**
Output/ Input ratio				
Grain/vegetables	1.5	1.4	1.1	0.9
Grain/ vegetables + Crop residue	2.9	3.4	2.6	1.4
Grain/ vegetables + Crop residue + Bund grass	3.0	3.5	2.6	1.4
Grain + Crop residue + Bund grass + Fruit	-	-	3.5	-
Grain/ vegetables + Crop residue + Bund grass + Tree fodder	-	3.6	-	1.6
Grain/ vegetables + Crop residue + Bund grass + Tree fodder + Fuelwood	-	4.0	-	1.9
Grain/ vegetables + Crop residue + Bund grass + Tree fodder + Fuelwood + Fruit	-	-	-	2.4

Values in parenthesis represent per cent contribution to total energy input and output of the respective parameters.

Table 31. Comparative monetary (Rs/ha/yr) input and output patterns for different crops grown in control and agroforestry systems at 380-500 m asl.

Parameters	Monetary			
	Control	AS	AH	AHS
Inputs				
Human labour	14,764.0 (62.4%)	15,847.0 (69.9%)	11,416.0 (66.7%)	14,459.0 (64.1%)
Bullock labour	3512.0 (14.8%)	3355.0 (14.8%)	2677.0 (15.6%)	2225.0 (9.9%)
FYM & Fertilizers	2929.0 (12.4%)	2779.0 (12.2%)	2530.0 (14.8%)	3236.0 (14.3%)
Seed	2460.0 (10.4%)	698.0 (3.1%)	495.0 (2.9%)	2636.0 (11.7%)
Total inputs	**23,665.0**	**22,679.0**	**17,118.0**	**22,556.0**
Outputs				
Grain/vegetables yield	41,355.0 (95.3%)	24,521.0 (73.9%)	15,490.0 (41.4%)	40,663.0 (66.1%)
Crop residue	1916.0 (4.4%)	2418.0 (7.3%)	1791.0 (4.8%)	768.0 (1.2%)
Fodder from weed & grasses of the bunds	123.0 (0.3%)	134.0 (0.4%)	138.0 (0.4%)	138.0 (0.2%)
Fodder from agroforestry trees	-	4825.0 (14.5%)	-	4357.0 (7.1%)
Fuelwood from agroforestry trees	-	1291.0 (3.9%)	-	1066.0 (1.7%)
Fruit from agroforestry trees	-	-	19,948.0 (53.4%)	14,541.0 (23.6%)
Total outputs	**43,394.0**	**33,189.0**	**37,367.0**	**61,533.0**
Output/ Input ratio				
Grain/vegetables	1.7	1.1	0.9	1.8
Grain/ vegetables + Crop residue	1.8	1.2	1.0	1.8
Grain/ vegetables + Crop residue + Bund grass	1.8	1.2	1.0	1.9
Grain + Crop residue + Bund grass + Fruit	-	-	2.2	-
Grain/ vegetables + Crop residue + Bund grass + Tree fodder	-	1.4	-	2.0
Grain/ vegetables + Crop residue + Bund grass + Tree fodder + Fuelwood	-	1.5	-	2.1
Grain/ vegetables + Crop residue + Bund grass + Tree fodder + Fuelwood + Fruit	-	-	-	2.7

Values in parenthesis represent per cent contribution to total monetary input and output of the respective parameters.

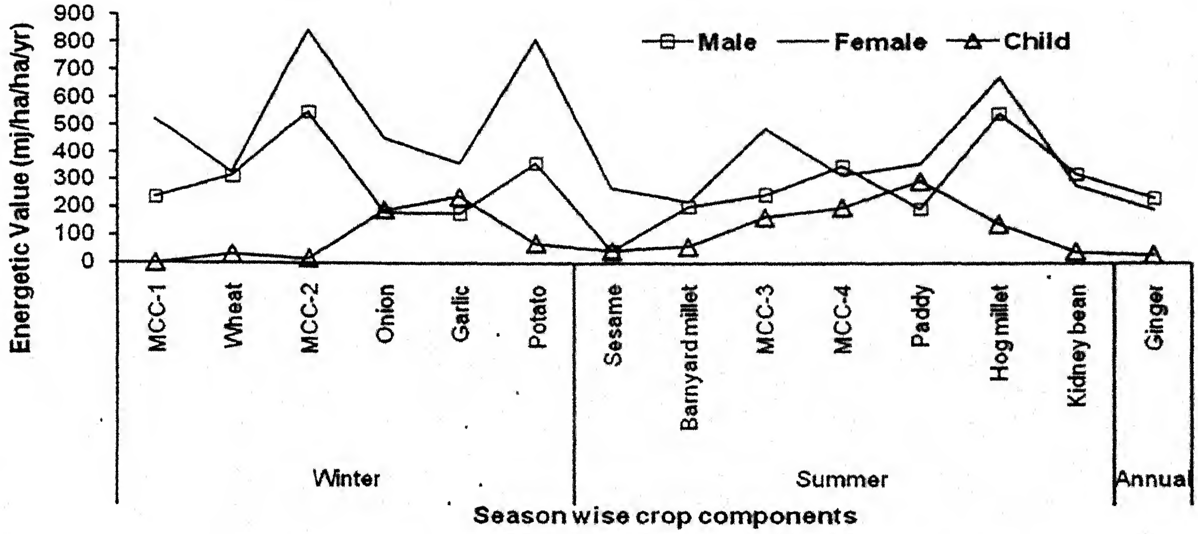
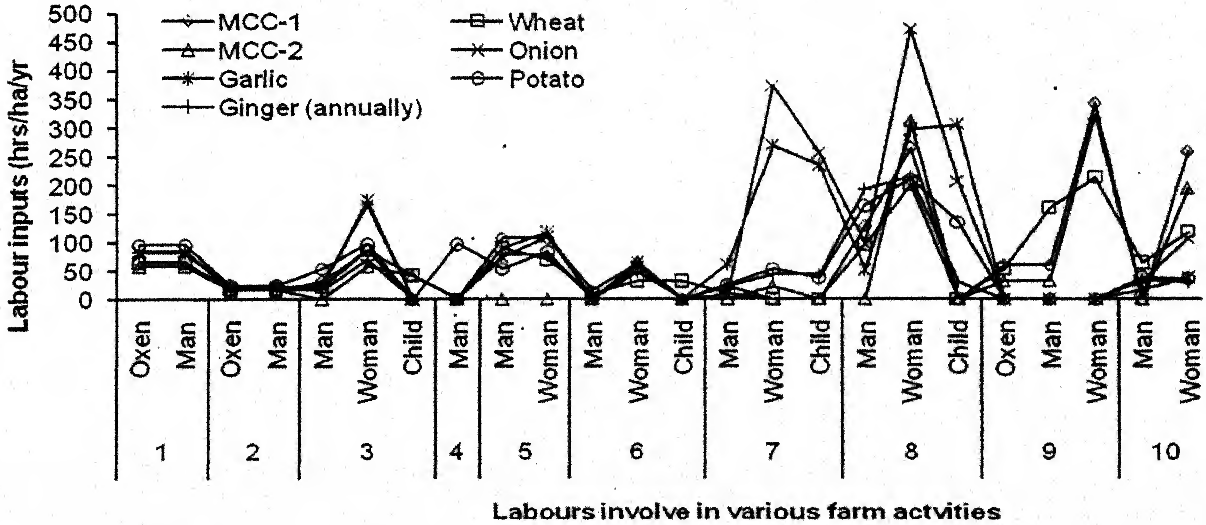
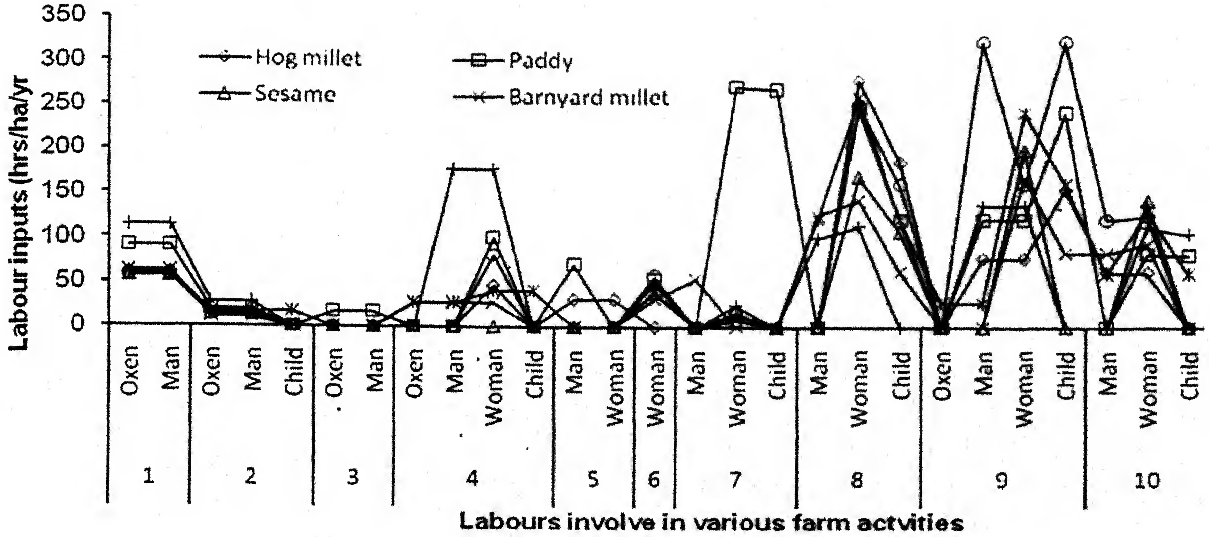


Fig. 1. Category wise energetic value (Mj/hr/ha/yr) of different crop components of without integration of trees at 380 to 500 m asl.



1. Ploughing; 2. Leveling; 3. Hoeing/weeding; 4. Bunding; 5. Irrigation; 6. Manuring; 7. Sowing/transplanting; 8. Harvesting; 9. Threshing/winnowing; 10. Transportation

Fig. 2. Details of the activities labour input (hrs/ha/yr) of cultivated land without integration of trees for various winter agricultural activities at 380 to 500 m asl.



1. Ploughing; 2. Leveling; 3. Puddling; 4. Hoeing/weeding; 5. Irrigation; 6. Manuring; 7. Sowing/transplanting; 8. Harvesting ; 9. Threshing & winnowing; 10. Transportation.

Fig. 3. Details of the activities labour input (hrs/ha/yr) of cultivated land without integration of trees for various winter agricultural activities at 380 to 500 m asl

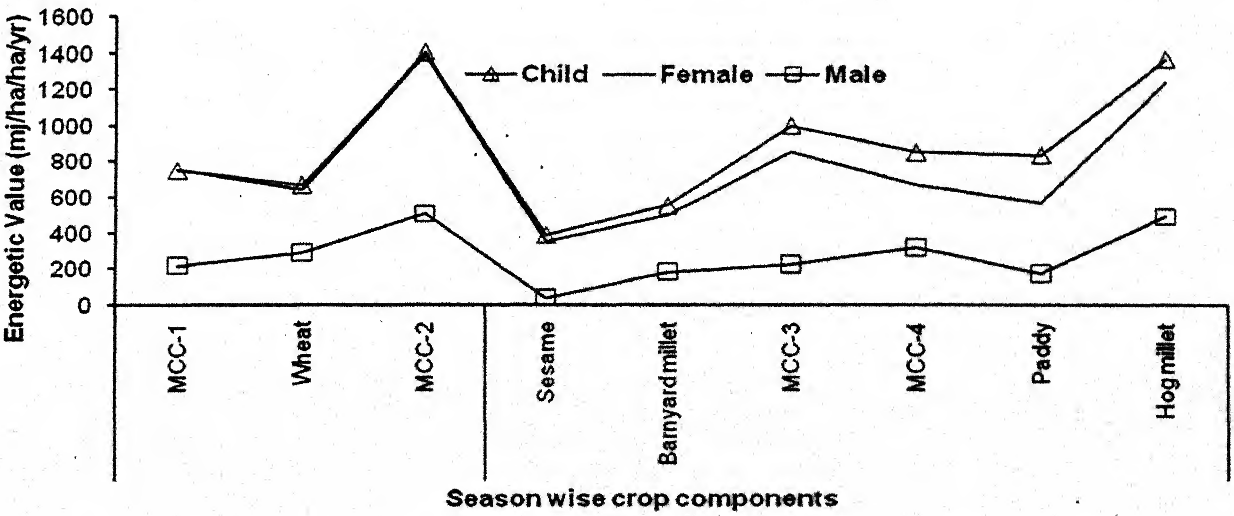
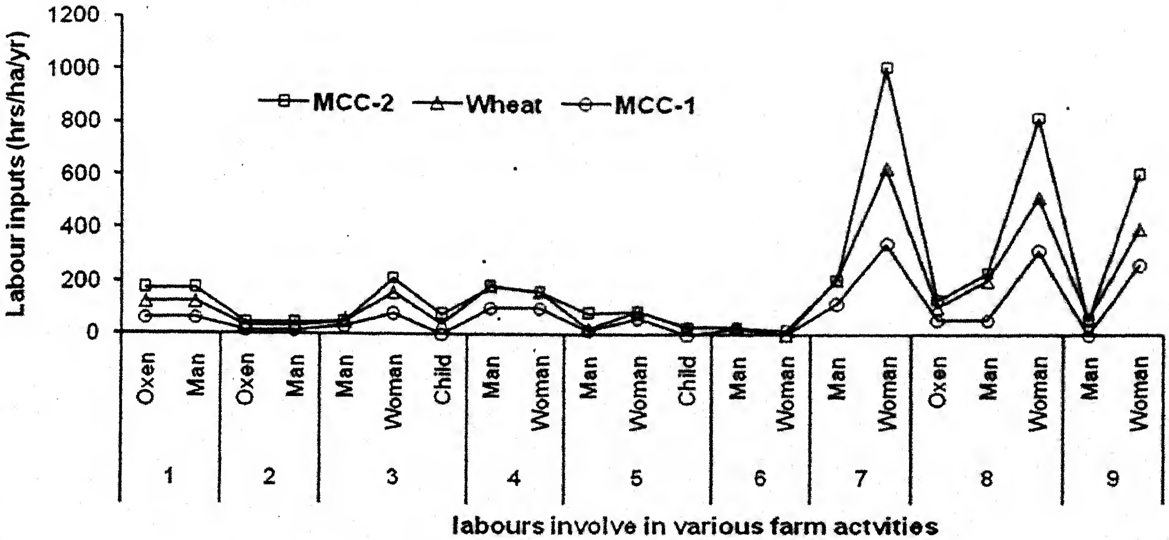
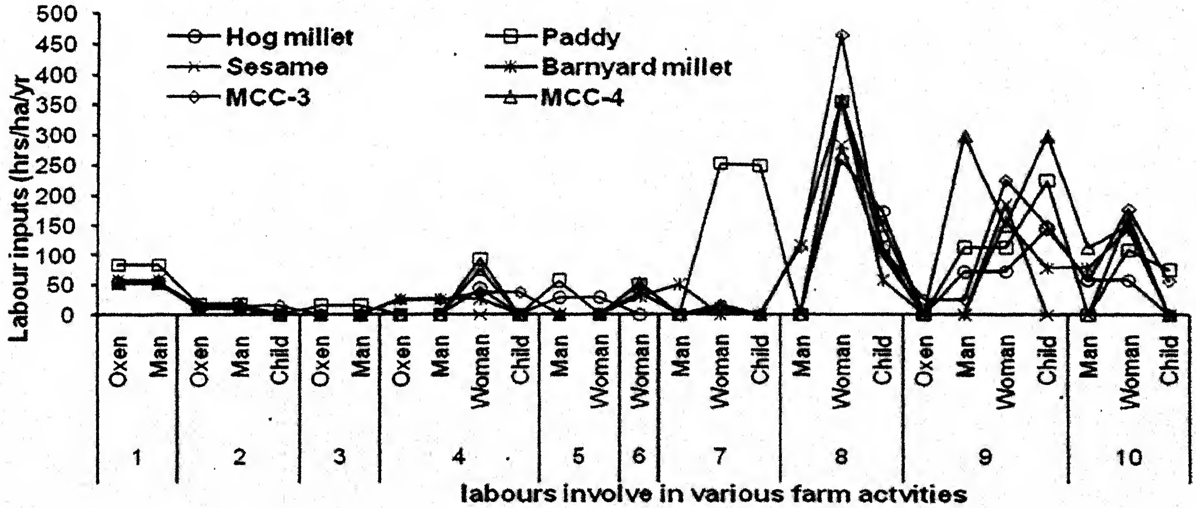


Fig. 4. Category wise energetic value (Mj/hr/ha/yr) of different crop components of agrisilvicultural agroforestry system at 380 to 500 m asl.



1. Ploughing; 2. Leveling; 3. Hoeing & weeding; 4. Irrigation; 5. Manuring; 6. Sowing & transplanting; 7. Harvesting & lopping; 8. Threshing & winnowing; 9. Transportation.

Fig. 5. Details of the activities labour input (hrs/ha/yr) of agrisilvicultural agroforestry system for various agricultural activities in winter at 380 to 500 m asl.



1. Ploughing; 2. Leveling; 3. Puddling; 4. Hoeing/weeding; 5. Irrigation; 6. Manuring; 7. Sowing/transplanting; 8. Harvesting & lopping; 9. Threshing & winnowing; 10. Transportation.

Fig. 6. Details of the activities labour input (hrs/ha/yr) of agrisilvicultural agroforestry system for various agricultural activities in summer at 380 to 500 m asl.

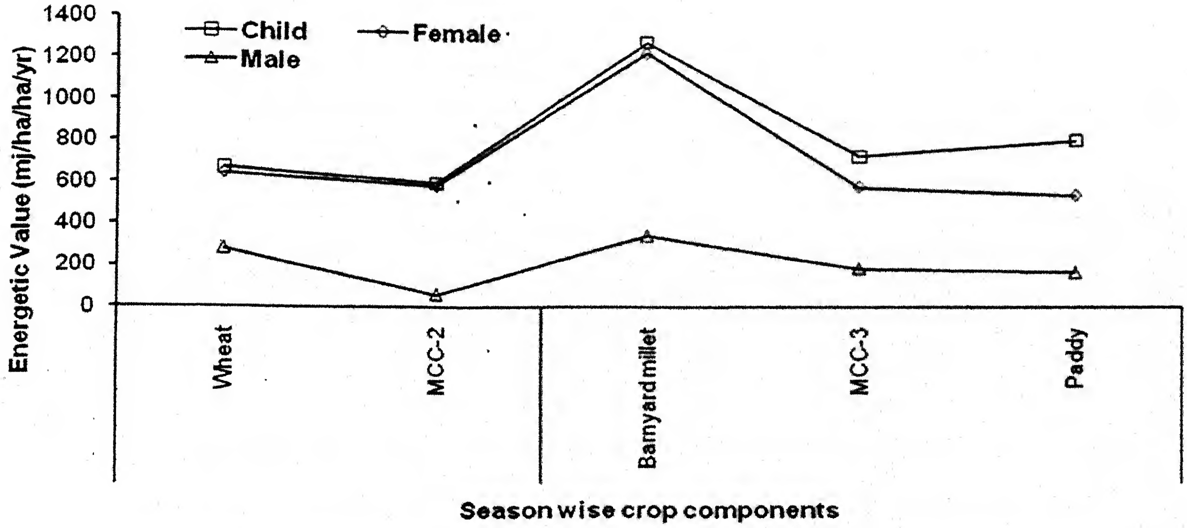
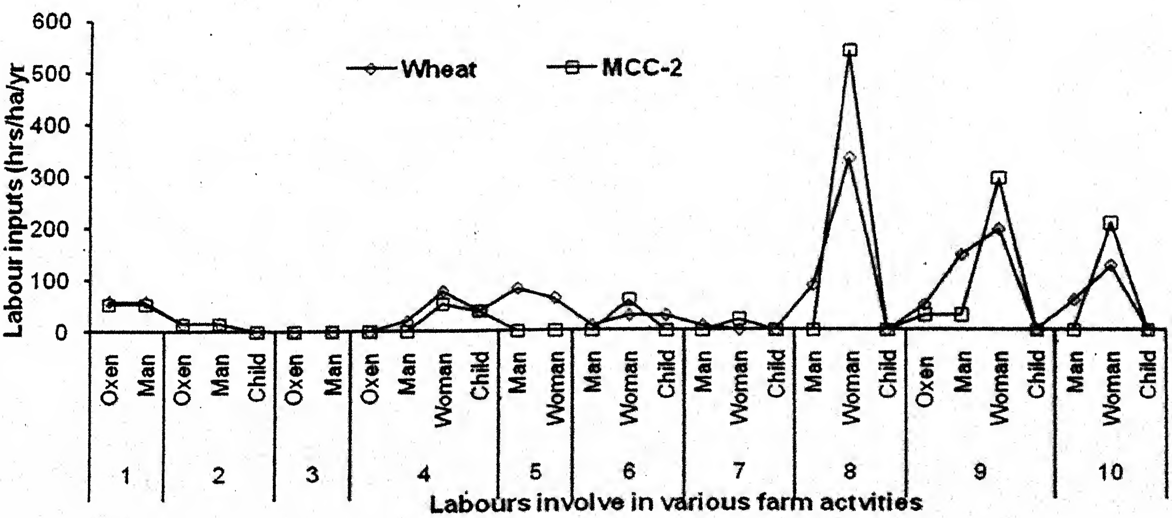
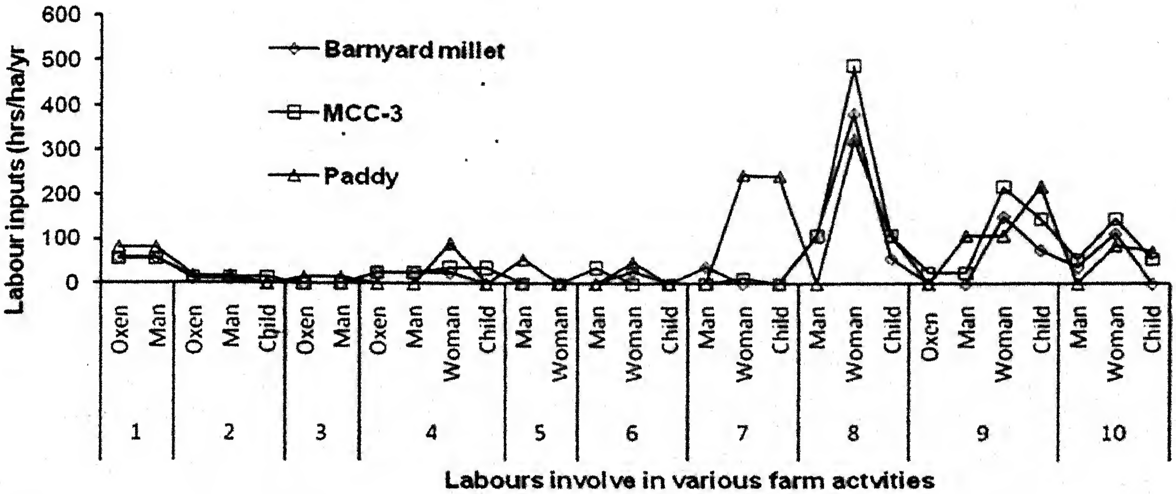


Fig. 7. Category wise energetic value (Mj/hr/ha/yr) of different crop components of agrihorticultural agroforestry system at 380 to 500 m asl.



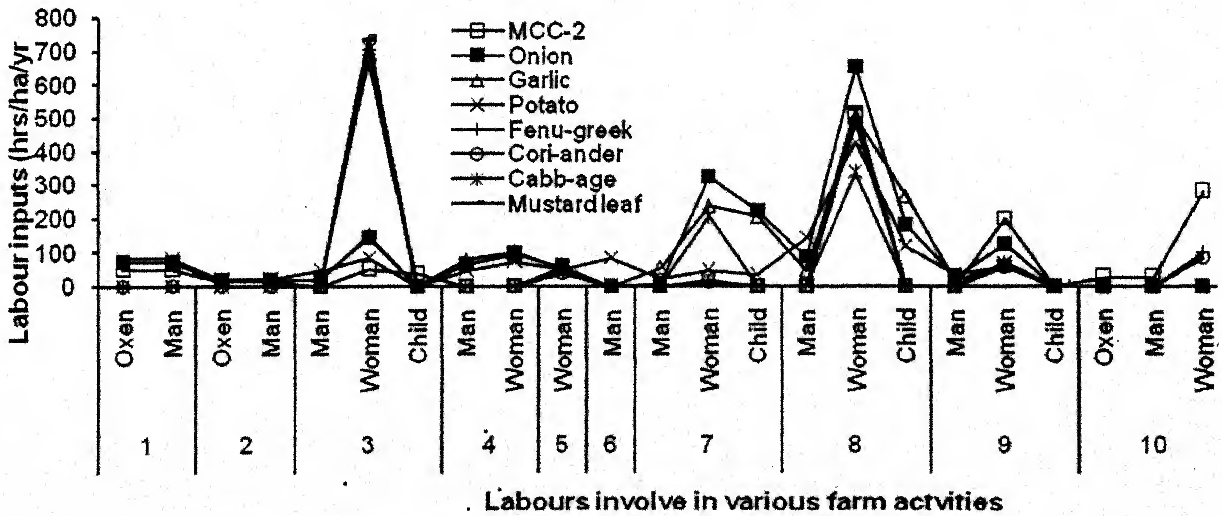
1. Ploughing; 2. Leveling; 3. Puddling; 4. Hoeing/weeding; 5. Irrigation; 6. Manuring; 7. Sowing/transplanting; 8. Harvesting & lopping; 9. Threshing & winnowing; 10. Transportation.

Fig. 8. Details of the activities labour input (hrs/ha/yr) of agrihorticultural agroforestry system for various winter agricultural activities at 380 to 500 m asl.



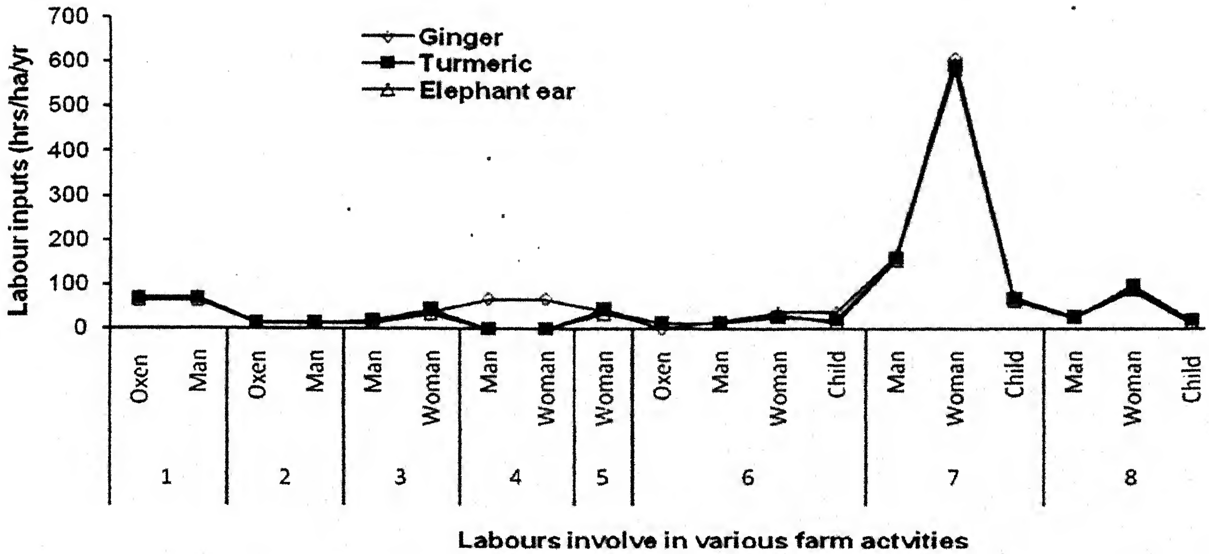
1. Ploughing; 2. Leveling; 3. Puddling; 4. Hoeing/weeding; 5. Irrigation; 6. Manuring; 7. Sowing/transplanting; 8. Harvesting & lopping; 9. Threshing & winnowing; 10. Transportation.

Fig. 9. Details of the activities labour input (hrs/ha/yr) of agrihorticultural agroforestry system for various summer agricultural activities at 380 to 500 m asl.



1. Ploughing; 2. Leveling; 3. Hoeing/weeding; 4. Irrigation; 5. Manuring; 6. Bunding (hrs); 7. Sowing/transplanting; 8. Harvesting & lopping; 9. Transportation; 10. Threshing & winnowing.

Fig. 10. Details of the activities labour input (hrs/ha/yr) of agrihortisilvicultural agroforestry system for various winter agricultural activities at 380 to 500 m asl.



1. Ploughing; 2. Leveling; 3. Hoeing/weeding; 4. Irrigation; 5. Manuring; 6. Sowing/transplanting; 7. Harvesting & lopping; 8. Transportation

Fig. 11. Details of the activities labour input (hrs/ha/yr) of agrihortisilvicultural agroforestry system for various annual Rhizome crops at 380 to 500 m asl.

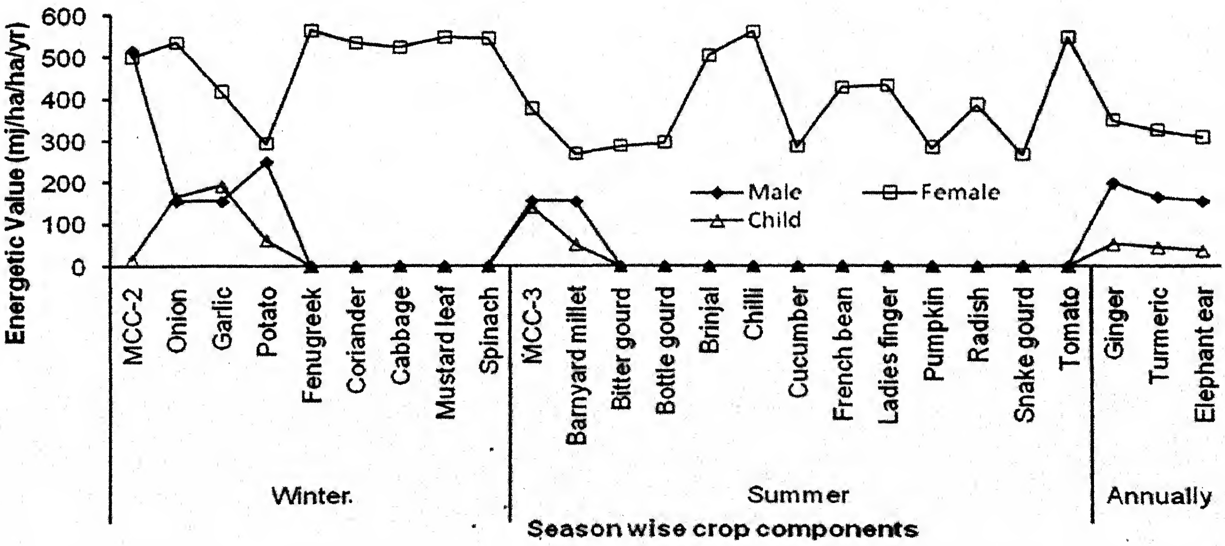


Fig. 12. Category wise energetic value (Mj/hr/ha/yr) of different crop components of agrihortisilvicultural agroforestry system at 380 to 500 m asl.

Table 31 depicts the data on comparative monetary budget of different agroforestry systems including control. On an average, for all the systems including control, the monetary input was > 62% by human labour. Bullock labour, FYM and fertilizers, and seed shared the rest. Inter-comparing the values between systems, no significant variations have been recorded, however, the total monetary input was highest (23,665 Rs/ha) in control and lowest (17,118 Rs/ha) in AH system, respectively. So far monetary output was concerned, it was highest (61,533 Rs/ha) in AHS and lowest (Rs. 33,189/ha) in AS system. Grain production contributed highest (95.3% of the total output) in control and lowest (41.5%) in AH system, indicating that the grain/vegetable productivity was higher in control plots compared to agroforestry plots. However, output through crop byproduct was recorded highest in AS (7.3%) system and lowest (1.2%) in AHS system. The fruit yield partitioned 53.4 and 23.2% of the total monetary output in AH and AHS systems, respectively. Similarly, the fuelwood yield from the trees cultivated in AS and AHS systems contributed 3.9-1.7% of the total monetary output, whereas, foliage from agroforestry trees showed 25.4-13.2% of the total monetary output in AS and AHS system. The output: input ratio has also been worked out keeping in view the different crops and crop byproducts. Taking into consideration the grain/vegetables productivity, output: input ratio was highest (1.8) in AHS and lowest in AH system (0.9). Calculating the total biological yield, the output: input ratio was calculated highest (2.7) to AHS system, followed by AH system (2.2) and however AS system showed the lowest output: input ratio, i.e., 1.5.

1000 to 1500 m altitude

Cropping patterns, crop combinations, labour inputs for various agricultural activities, fertilizer inputs, eco-energetic analysis and cost-benefit analysis at 1000 to 1500 m altitude in control plots were depits on table 32 to 36. On an average, six different crops or crop combinations were grown as winter crops and six nos. of crops during summer. Wheat and barley were the major winter cereal crops, whereas paddy, barnyard millet, finger millet and soyabean were the major summer crops. Wheat was grown either as a sole crop or intercropped with mustard. Similarly barley was grown either as a sole crop or association with lentil. During summer, finger millet was grown either as a sole crop or

intercropped with black gram, horse gram, cowpea and soyabean. Rest of the crops was cultivated as a mono crop.

Total human labour input (hrs/ha/yr) was recorded highest (1725.4) for onion cultivation, followed by maize (1215.5). Among various crop combinations, minimum human labour input was required for soyabean cultivation (593.3 hrs/ha/yr). The bullock labour, was required highest (130.8 hrs/ha/yr) in MCC 1 cultivation, followed by barnyard millet (130.0 hrs/ha). On an average, 985.5 and 884.9 hrs of human labour/ha were required for winter and summer crops, respectively, irrespective of crops or crop compositions. Females contributed, respectively, 63.9 and 52.5% of the total human labour during winter and summer crops. The bullock labour was required only 103.3 and 106.3 hrs/ha for winter and summer crops (fig.13). Thus human labour was consumed 8 to 9-fold higher for per hectare cultivation compared to bullock labour. Barley, finger millet and barnyard millet were grown only in rainfed agriculture. The land was left fallow after cultivation of these crops (Table 32).

Ploughing and leveling operation during winter cropping was exclusively conducted by the males, besides, hoeing/weeding, irrigation, manuring, sowing/transplanting, harvesting, threshing and transportation. Bullock labour was mainly used for ploughing, leveling and threshing of wheat and barley. Similarly, during winter cropping, male labour was engaged for ploughing, leveling, hoeing/weeding (particularly in barnyard millet and finger millet cultivation), threshing and transplantation of the grains. Females contributed for majority of the agricultural operations (fig. 14).

Seed rate input and fertilizer input of various agricultural crops has been given in Table 33. Potato crop had high seed (tuber) input rate (1400.0 kg/ha) compared to cereal/pulses/oilseed crops. On an average, the major crops like wheat, barley, onion, paddy, maize, barnyard millet, finger millet and soyabean, respectively, had seed rate of 114.2, 100.0, 11.5, 55.9, 44.4, 18.0, 17.5 and 61.5 kg/ha. The range of FYM application varied from 14.0 (for barnyard millet) to 22.3 q/ha (for paddy). Farmers used higher amount of FYM (19.0 q/ha/yr) for cultivation of MCC 1, wheat, onion, paddy and maize; and the amount was reduced almost by 40 % in case of millets cultivation.

Crops productivity (q/ha) has been shown in table 34. On an average, the productivity of wheat was recorded to be 20.2 q/ha. Paddy showed the average grain yield of 16.6 q/ha. Maize yield was recorded to be 24.0 q/ha. The grain productivity of staple food crops like barley, barnyard millet, finger millet and soyabean was recorded to be 11.9, 13.4, 12.8 and 10.3 q/ha. The crop byproduct of all the aforesaid crops has been used as a fodder for cattle. The crop byproduct yield was, respectively, 32.9, 19.2, 29.6, 47.3, 32.8 and 35.3 q/ha for wheat, barley, paddy, maize, barnyard millet and finger millet cultivation.

Total energy input (MJ/ha/yr) of human labour for various agricultural operations showed a range of 286.4 (soyabean cultivation) to 718.9 (onion cultivation). The human energy consumption was also found comparatively low for MCC 1, potato, paddy, MCC 3 and maize (range 460.8 to 575.3 MJ/ha). Most of the agricultural operations belonged to heavy works. Mixed crop composition or mono cropping did not exhibit marked variation in total energy requirement of human labour (fig. 15).

Total energy input was highest (91%) through FYM & fertilizer application, irrespective of crops and crop compositions. The annual energy input (MJ/ha/yr) of human labour, bullock labour and seed was, respectively, 512.7, 795.8 and 1500.6, irrespective of crop and crop composition. On the other hand, the energy output was, respectively, 38.9, 60.5 and 0.52% through grain/vegetable yield, crop byproduct and fodder from weeds and grasses of the bunds. Among various winter crops, the total energy input was recorded highest for crop composition of wheat + mustard. (36573.16 MJ/ha/yr) so as to total energy outputs (62997.8 MJ/ha). In case of summer crops, the annual energy input was recorded highest (36146.5 MJ/ha) for paddy cultivation, followed by maize (34207.7 MJ/ha). Among various winter and summer crops, lowest energy input was recorded for barnyard millet cultivation (21852.1 MJ/ha). The total energy output for winter crops, however, was recorded highest for wheat (78754.2 MJ/ha) followed by MCC 1 (62997.8 MJ/ha).

Among winter crops, energy output: input ratio was recorded highest (2.5) to wheat, followed by barley (2.1). Lowest output: input ratio, however, was recorded to potato cultivation (1.1). Among various summer crops, barnyard millet exhibited the highest output: input ratio (4.5), followed by finger millet (3.3)

and maize (3.2). Soyabean cultivation, however, exhibited the lowest output: input ratio, *i.e.*, 1.5 (Table 35).

The total monetary input has been worked out as Rs. 12,722/ha. On an average, the monetary input was highest (54.5% of the total input) through human labour. Bullock labour, FYM and seed, respectively, showed 19.1, 17.6 and 8.7% of the total monetary inputs. Total monetary output was recorded as Rs. 20,526/ha. Inter-comparing the monetary input and output during different cropping seasons, it has been recorded that the monetary input was, respectively, 12,260 and 9447 Rs/ha to winter and summer crops with monetary output of Rs. 24,997 and 14,049. The net monetary output: input ratio was 1.8 and 1.4, respectively, to winter and summer crops. Among various winter crops, onion cultivation exhibited highest output: input ratio (3.7), followed by potato (2.2) cultivation. Among summer crops, soyabean had highest output: input ratio (2.1), followed by maize cultivation (1.8) (Table 36).

Table 37 depicts the data on phytosociological parameters studied for different tree-crops found in different agroforestry systems. In AS system, *Celtis australis* exhibited highest values of relative frequency, relative density and relative dominance, which has resulted to have highest IVI, whereas *Melia azedarach* was having lowest value in all the respects? Among various fruit tree species, *Citrus sinensis* exhibited relatively higher values of relative frequency, relative density as well as IVI in AH system, whereas lowest values in all the respect were recorded in *Prunus armeniaca*. Relative dominance in this system was highest to *Juglans regia* although, it did not had much influence on IVI value. Among the silvicultural component of AHS system, *C. australis* exhibited highest values of relative frequency, relative density and relative dominance, which has resulted to have highest IVI, whereas *M. azedarach* was having lowest values in all the respects. Among the horticultural component, *J. regia* had the highest rate of occurrence with relative dominance, which have resulted to have highest IVI. Lowest values in all the respects were observed in *Pyrus malus.*

On an average, 10 multipurpose tree species (MPTS) and 12 fruit tree species were cultivated by the farmers in or around agricultural fields in rainfed situation at this altitude. Fuel, fodder, timber and fruit yield has been recorded for

each MPTS and fruit tree species. The average fodder yield was recorded highest (19.3 kg/tree/yr) in *C. australis* and lowest (8.5 kg/tree/yr) in *Ficus cunia*. Similarly, the fuelwood yield was also recorded highest in *C. australis* (10.6 kg/tree/yr) and lowest (4.6 kg/tree/yr) in *F. cunia*. The fibre yield (extracted from *Grewia optiva*) was 0.35 kg/tree/yr. Species like *M. azedarach*, *Ougeinia oojeinensis*, *Quercus leucotrichophora* and *Toona ciliata* were also used as timber species. On an average, the timber volume per tree was recorded highest (0.48 m^3) in *T. ciliata*, followed by *M. azedarach* (0.28 m^3). Lowest timber volume, however, was recorded in *O. oojeinensis* (0.10 m^3) (Table 38).

Among various MPTS, *C. australis, Ficus auriculata, G. optiva, M. azedarach* and *Morus alba* have been cultivated in both AS and AHS systems. On an average, 136 nos. of trees were cultivated per hectare of land in AS system. Similarly, in AHS system, the total density of trees was recoded to be 171 per hectare, irrespective of species. The tree density in AH system was recorded to be 125 plants/ha. Inter-comparing the tree density of MPTS at species level, maximum density was noticed for *C. australis* (32.0), followed by *O. oojeinensis* (23.0) whereas, lowest tree density was recorded for *F. cunia* (5.2). Similarly, in case of AH system, tree density was highest for *Citrus sinensis* (32.3), followed by *Musa paradisica* (19.3). Among various fruits tree species, lowest density however, was recorded for *Prunus armeniaca* (2.0).

The total tree fodder yield was recorded to be 21.7 and 9.0 q/ha, respectively, in AS and AHS systems. Similarly, the firewood yield was recorded to be 11.8 and 5.3 q/ha, respectively, from AS and AHS system. The total timber production was recorded highest in *T. ciliata* (5.0 m^3/ha) and lowest (0.46 m^3/ha) in *M. azedarach* whereas, productivity of the grass from the bunds of agricultural fields ranged from 1.1 to 1.2 q/ha/yr (Table 38.1).

Table 39 to 43 represents the different cropping patterns, crop combinations, labour inputs for various agricultural activities, fertilizer inputs, eco-energetic analysis and cost-benefit analysis of AS system at 1000 to 1500 m asl. Wheat and barley were the major winter cereal crops, whereas, paddy, barnyard millet and finger millet were the main summer crops. Wheat was grown either as a sole crop or intercropped with mustard. Similarly, barley was grown either as a sole crop or in association of lentil. During summer, finger millet was

cultivated either as a sole crop or intercropped with cowpea, horse gram, soyabean and amaranth. Rests of the crops were cultivated as a mono crop. On an average, crop combinations were same either in control or agroforestry plots.

Fig. 16 and fig. 17 were reveiled that the total labour input (hrs/ha/yr) for different crops grown in agrisilvicultural agroforestry systems for various crops activities during winter and summer session. Among winter crops, MCC-1 required highest human labour input (1048.4 hrs/ha). Similarly, MCC 3, followed by paddy had comparatively higher labour input compared to other crops. Minimum human labour input, however, was required for finger millet cultivation (860.7 hrs/ha/yr). The bullock labour was required highest (122.5 hrs/ha/yr) in MCC 1 cultivation, followed by barnyard millet (121.8 hrs/ha/yr). On an average, 907.3 and 1073.4 hrs of human labour was required for per hectare cultivation during winter and summer crops, respectively, irrespective of crops or crop compositions. Females contributed, respectively, 79.5 and 65.6% of the total human labour during winter and summer crops. The bullock labour was required only 103.6 and 113.2 hrs/ha, respectively, for winter and summer crop's cultivation. Barley, finger millet and barnyard millet were grown only in rainfed agriculture and the fields were left fallow after cultivation of these crops (Table 39).

Ploughing and leveling operations during winter cropping were exclusively conducted by males. They also contributed labour for hoeing/weeding, irrigation, manuring, sowing/transplanting, harvesting, tree lopping, threshing and winnowing, and transportation/carrying. Ploughing operation consumed maximum bullock labour (59.3 hrs/ha), followed by threshing (27.3 hrs/ha). During summer cropping, male labour was engaged for ploughing, leveling, hoeing/weeding (particularly in paddy, barnyard millet and finger millet cultivation), manuring, threshing and transportation of the grains. Females contributed in majority of the agricultural operations.

Seed rate input of various agricultural crops has been given in Table 40. Wheat and barley crops showed high seed rate (kg/ha) compared to other seed crops. On an average, seed rate for wheat, barley, paddy, barnyard millet and finger miller was respectively, 107.0, 93.8, 52.4, 16.9 and 16.4 kg/ha. The range of FYM application varied from 12.7 (for barley) to 21.9/ha (for paddy). Farmers

used higher amount of FYM (16-22 q/ha) for cultivation of MCC 1, wheat, paddy and MCC 2. The FYM application was reduced almost by 30% in case of millets cultivation (Table 40).

Crop productivity (q/ha) in AS system has been shown in table 41. On an average, wheat productivity was 18.4 q/ha. Paddy showed the average grain yield of 12.4 q/ha. The grain productivity of staple food crops like barley, barnyard millet and finger millet was recorded to be 10.1, 11.6 and 10.1 q/ha, respectively. Barley and finger millet was also grown in the mixed crop composition and the average productivity was 6.4 and 2.2 q/ha, respectively. The crop byproduct yield was, respectively 29.9, 18.8, 19.9, 30.8 and 28.1 q/ha for wheat, barley, paddy, barnyard millet and paddy cultivation.

Total energy input (MJ/ha/yr) of human labour for various agricultural operations showed a range of 397.1 (barley cultivation) to 632.9 (finger millet + black gram + horse gram + cowpea + soyabean). The human energy consumption was also found comparatively low for cultivation of MCC 1, MCC 2 and paddy (range 473.2 to 505.4 MJ/ha). Most of the agricultural operations belonged to heavy works. Mixed crop composition or mono cropping did not exhibit marked variation in total energy requirement of human labour (fig.18).

Comparative energy budget for various agricultural crops has been shown in Table 42. Among various inputs, it has been observed that more than 91% energy input was contributed by FYM, irrespective of crops or crop compositions. The annual energy input (MJ/ha/yr) through human labour, bullock labour and seed was, respectively, 536.8, 750.8 and 1191.8, irrespective of crop and crop compositions. On the other hand, the energy output was, respectively, 26.5, 45.3, 0.5, 10.6 and 17.1% through grain, crop byproduct, fodder from weed and grasses of the bunds, tree fodder and fuelwood. Among various winter crops, total energy input was recorded highest for crop composition of wheat + mustard (34429.8 MJ/ha/yr) so as to total energy output (72029.5 MJ/ha/yr). In case of summer crops, the annual energy input was recorded highest (34025.9 MJ/ha/yr) for paddy cultivation. Among various summer and winter crops, lowest energy input was recorded for barnyard millet cultivation (20657.0 MJ/ha/yr). Among various winter crops, the total energy output was recorded highest for wheat (104153.3 MJ/ha/yr), followed by barley (75426.4 MJ/ha/yr). Among winter

crops, energy output: input ratio was recorded highest (3.6) to barley, followed by wheat (3.56). Lowest output: input ratio, however, was recorded to MCC 2 cultivation (2.5). Among summer crops, barnyard millet exhibited the highest output: input ratio (4.6), followed by finger millet cultivation (4.3). Paddy cultivation, however, exhibited the lowest output: input ratio (2.0).

Based on crop rotation, the total monetary input has been worked out as Rs. 12,265/ha. On an average, the monetary input was highest (60.5% of the total input) through human labour. Bullock labour, FYM, and seed, respectively, showed 18.9, 15.9, and 4.7% of the total monetary inputs. So far total monetary output was concerned, it has been recorded as Rs. 18,970/ha, irrespective of cropping seasons and 58.3% of the total output was contributed by grain productivity. Rest was shared by green fodder (bund grass and tree leaves), dry fodder, and fuelwood, irrespective of cropping patterns and cropping seasons. Inter-comparing the monetary input and output during different cropping seasons, it has been recorded that the monetary input was, respectively, 10,683 and 10,782 Rs/ha to winter and summer crops. The net monetary output: input ratio was 1.6 and 1.5, respectively, to winter and summer crops. Among various winter crops, wheat cultivation exhibited the highest (2.2), and MCC 1 the lowest (1.3) output: input ratio. Among summer crops, MCC 3 had highest output: input ratio (1.8), followed by barnyard millet cultivation (1.5) (Table 43).

Table 44 to 48 represents the cropping patterns, crop combinations, eco-energetic analysis and cost benefit analysis of AH system. On an average, two different crops or crop combinations were grown as winter crops and four nos. of crops during summer. Wheat was grown as a sole crop, whereas barley was inter-cropped with lentil. During summer, finger millet was grown either as a sole crop or intercropped with black gram, horse gram, cowpea, and soyabean. Total human labour input (hrs/ha) was recorded highest (1319.8) for MCC 3 cultivation, followed by paddy (991.7). Among various crop combinations, minimum human labour input was required for wheat cultivation (785.1 hrs/ha). The bullock labour (hrs/ha) was required highest (120.0) in barnyard millet cultivation followed by paddy (113.3) (fig. 19). On an average, 875.2 and 1000.7 hrs of human labour was required for per ha cultivation during winter and summer crops, respectively, irrespective of crops or crop combinations in AH system. Females contributed, respectively, 87.6 and 64.5% of the total human

labour during winter and summer crops. The bullock labour was required only 95.1 and 109.5 hrs/ha for winter and summer crops (Table 44).

Ploughing and leveling operation during summer cropping was exclusively conducted by males. They also contributed labour for hoeing/weeding, manuring, sowing/transplanting, harvesting, fruit picking, threshing and winnowing, and transportation. Bullock labour was mainly used for ploughing and leveling. However, it was also employed for threshing of wheat, barley, barnyard millet and finger millet. On an average, the seed rate for wheat, barley, barnyard millet, finger millet and paddy, was estimated to be 102.7, 75.0, 16.2, 15.7 and 50.4 kg/ha, respectively. The range of FYM application varied from 16.7 (for wheat) to 22.5 q/ha (for paddy). FYM was also used in fruit trees @ 3.0 kg/tree with highest in *Citrus sinensis* (0.97 q/ha) and lowest (0.06 q/ha) in *Prunus armeniaca* (Table 45).

Crop productivity (q/ha) in AH system has been shown in Table 46. The average wheat productivity was 11.1 q/ha. Paddy showed the average grain yield of 8.2 q/ha. The grain productivity of staple food crops like barley, barnyard millet and finger millet was recorded to be 6.0, 8.0 and 9.0 q/ha. The crop byproduct yield was, respectively, 16.6, 8.4, 18.2, 20.4 and 16.0 q/ha, respectively, for wheat, barley, barnyard millet, finger millet and paddy.

Total energy (MJ/ha/yr) of human labour for various agricultural operations showed a range of 365.5 (wheat cultivation) to 596.2 (MCC 3 cultivation). Mixed crop composition or mono cropping did not exhibit marked variation in total energy requirement of human labour (fig. 20).

Comparative energy budget for various agricultural crops has been shown in Table 47. Among various inputs, it has been observed that FYM alone contributed > 90% energy. The annual energy input of human labour, bullock labour and seed was, respectively, 532.3, 761.2 and 1045.3 MJ/ha/yr, irrespective of crop and crop compositions. On the other hand, the energy output was, respectively, 18.9, 33.1, 0.5 and 47.5% through grain, crop byproduct, fodder from weed and grasses of bunds and fruits. Among various winter and summer crops, total energy input was recorded highest (34795.0 MJ/ha/yr) for paddy cultivation, followed by MCC 3 (30457.6 MJ/ha/yr). Highest energy output was recorded for MCC 3 (99515.3 MJ/ha/yr) and lowest to paddy (45953.8

MJ/ha/yr). Energy output: input ratio was recorded highest to finger millet (3.5). Lowest value of output: input ratio was recorded in paddy cultivation (1.3).

The monetary input and output for AH system has been depicted in table 48. Based on crop rotation, the total monetary input has been worked out as Rs. 12,375/ha. On an average, the monetary input was highest (59.2% for the total input) through human labour. Bullock labour, FYM and seed, respectively, contributed 19.0, 17.4 and 4.3% to the total monetary inputs. So far total monetary output was concerned, it has been recorded as Rs. 31,524/ha, and 27.3% of the total output was achieved through grain yield. Interestingly, 69.5% of the total monetary output was obtained through fruits. Inter-comparing the monetary input and output during different cropping seasons, it has been recorded that the monetary input was, respectively, 10,068 and 10,510 Rs/ha to winter and summer crops with the net monetary of Rs. 26,444 and 16,184/ha, accordingly. The net monetary output: input ratio was 2.6 and 2.5, respectively, to winter and summer crops. Among various winter and summer crops, MCC 3 cultivation exhibited highest output: input ratio (3.0), followed by finger millet (2.9). Lowest output: input ratio was recorded for paddy cultivation (1.2).

Table 49 to 53 represents the different cropping patterns, eco-energetic analysis and cost-benefit analysis of AHS system at 1000 to 1500 m altitude. Out of total 16.7 ha of cultivated area, *i.e.*, AS, AH and AHS systems were practiced, respectively, over 24.3, 2.0 and 8.6% area. Compared to AS and AH system, seasonal vegetables were mainly cultivated in AHS system. While elephant ear was grown on annual basis; bulb and tubers like onion and potato and leafy vegetable like mustard leaf were the major winter vegetable crops. Major summer vegetables include the cultivation of brinjal, chilli, french bean, ladies finger and tomato in AHS system.

Fig. 21 reveiled that the total human labour input (hrs/ha) was recorded highest (1788.3) for onion cultivation, followed by tomato (1379.7). Among various crop combinations, minimum human labour input was required for pumpkin cultivation (620.0 hrs/ha). The bullock labour, however, was required highest (82.1 MJ/ha/yr) in onion cultivation and lowest (69.6 MJ/ha/yr) in maize cultivation. On an average, 1447.5 and 1021.1 hrs of human labour was required for cultivation of winter and summer crops, respectively, irrespective of crops or

crop compositions. Females contributed, respectively, 73.6 and 93.9% of the total human labour input during winter and summer crops (Table 49).

In this system, male labour was mainly engaged for ploughing and leveling. However, hoeing/weeding, harvesting, threshing and transportation during winter crops was also done by male. Rest of the operations were exclusively conducted by female and child labour. During annual crops, male and bullock labour was engaged for ploughing, leveling sowing/transplanting in elephant ear.

Seed rate input of various agricultural crops/vegetables has been given in Table 50. Potato and elephant ear, respectively, showed the seed rate of 1265.0 and 1310.0 kg/ha. On an average, the major transplanted vegetable crops like onion, brinjal, chilli and tomato, respectively, had the seed rate of 10.3, 0.7, 0.9 and 0.7 kg/ha. Other vegetable crops exhibited the seed rate > 3.0 kg/ha. The range of FYM application varied from 11.0 (for pumpkin) to 21.5 q/ha (for mustard leaf). FYM was also used in fruit trees @ 3.0 kg/tree with highest in *Juglans regia* (0.85 q/ha) and lowest (0.10 q/ha) in *Prunus armeniaca*.

Crop/vegetable productivity (q/ha) has been shown in Table 51. Among vegetables, highest productivity was recorded for radish cultivation (150.8 q/ha), followed by elephant ear (131.5 q/ha), pumpkin (98.9 q/ha) and mustard leaf (93.2 q/ha). Maize, however, showed the lowest grain productivity (15.1 q/ha). The crop byproduct yield through maize was 26.4 q/ha.

Total energy input (MJ/ha) of human labour for various agricultural operations showed a range of 261.9 (bottle gourd cultivation) to 581.5 (maize cultivation) in AHS system. Among various inputs, it has been observed that more than 93% energy input was contributed by FYM, irrespective of crops/vegetables. The annual energy input (MJ/ha) of human labour, bullock labour and seed was, respectively, 862.2, 445.2 and 2240.4, irrespective of crops/vegetables. On the other hand, the energy output was, respectively, 42.7, 11.0, 0.4, 3.3, 8.3 and 34.3% through grain/vegetable yield, crop byproduct, fodder from weed and grasses of the bunds, tree fodder, fuelwood, and fruit yield. Among various crops, total energy input was recorded highest (35173.0 MJ/ha/yr) for potato cultivation, followed by elephant ear (32746.6 MJ/ha/yr).

Lowest energy input was recorded in pumpkin cultivation (16448.5 MJ/ha/yr) (Table 52).

Total energy input for winter, summer and annual crops, however, was recorded highest for elephant ear cultivation (90340.7 MJ/ha/yr), followed by french bean (89820.5 MJ/ha/yr), and lowest in ladies finger (29890.7 MJ/ha/yr) cultivation. Energy output: input ratio was recorded highest (3.1) to french bean, followed by elephant ear (2.8). Lowest output: input ratio, however, was recorded to ladies finger (1.0) cultivation (fig. 22).

Based on crop rotations, the total monetary input has been worked out as Rs. 21,311/ha. On an average, the monetary input was highest through human labour (61.9% for the total input). Bullock labour, FYM and seed, respectively, showed 6.6, 15.6 and 16.0% of the total monetary inputs. So far total monetary output was concerned, it has been recorded as Rs. 78,642/ha and 69.1% of the total output was obtained through grain/vegetables and rest was shared by green and dry fodder, fuelwood and fruits, irrespective of cropping patterns. Inter-comparing the monetary input and output during different cropping seasons, it has been recorded that the monetary input was, respectively, 15,110 and 8,797 Rs/ha to winter and summer crops. For winter crops, monetary output: input ratio ranged from 3.1 to 3.3. Among the summer crops, radish cultivation in AHS system showed the highest output: input ratio (9.95), followed by tomato (9.94) and bottle gourd (9.3) cultivation. Lowest output: input ratio was recorded for maize cultivation (1.9). The monetary output was Rs. 47,837 and 53,335/ha, respectively, to winter and summer crops. The monetary output: input ratio was 3.2, 5.9 and 5.0, respectively; to winter, summer and annual crops cultivation (Table 53).

Table 54 depicts the data on comparative energy budget of different agroforestry systems including control. On an average, for all the systems including control, the energy input was > 91% through FYM and fertilizers, and rest was shared by seed, human and bullock labour. Inter-comparing the values between systems, no significant variations have been recorded, however, the total energy input was highest (51985.8 MJ/ha/yr) for AHS and lowest (30194.3 MJ/ha/yr) for AH system, respectively. So far output was concerned, grain/vegetable yield contributed 18.9 to 42.7% in different AFS compared to

39.0% in control. Output through crop residue was recorded highest in control (60.5%) and lowest (11.0%) in AHS system. The fruit yield partitioned 47.5 to 34.3% of the total energy output in AH and AHS systems. Similarly, the fuelwood yield in AS and AHS systems contributed 17.1- 8.3% of the total energy output, whereas, foliage from agroforestry trees showed 10.6-3.3% of the total energy outputs. The total energy output, however, was recorded highest in AHS system (115611.7 MJ/ha/yr) and lowest in control (79571.1 MJ/ha/yr). The output: input ratio has also been worked out keeping in view the different crops and crop byproducts. Taking into consideration the grain/vegetables productivity, output: input ratio was highest (0.96) in control and lowest in AH system (0.51). Calculating the total biological yield, the output: input ratio was highest (2.85) to AS system, followed by AH system (2.72). AHS system, however, showed lowest output: input ratio, *i.e.*, 2.2.

Table 55 depicts the data on comparative monetary budget of different agroforestry systems including control. On an average, for all the systems including control, the monetary input was 54% through human labour and rest was shared by bullock labour, FYM and seed. Inter-comparing the values between systems, no significant variations have been recorded, however, the total monetary input was highest (21,311 Rs/ha) for AHS system and lowest (12,265 Rs/ha) for AS system, respectively. So far monetary output was concerned, it was highest (78,642 Rs/ha) for AHS and lowest (18,970/ha) for AS system. Grain/vegetable productivity contributed highest (92.9% of the total output) in control and lowest (27.3%) in AH system. However, output through crop byproduct was recorded highest in control (6.6%) and lowest (0.6%) in AHS system. The fruit yield partitioned 69.5 and 26.2% of the total monetary output in AH and AHS systems, respectively. Similarly, the fuelwood yield of AS and AHS systems, respectively, contributed 7.7 to 0.9% of the total monetary output. Tree fodder showed 29.1–3.1% of the total monetary outputs accordingly in the same systems. The output: input ratio has also been worked out keeping in view the different crops and crop byproducts. Taking into consideration the grain/vegetable productivity, output: input ratio was highest (2.5) in AHS and lowest in AH system (0.7). Calculating the total biological yield, the output: input ratio was highest (3.7) to AHS system, followed by AH system (2.5). AS system, showed (1.5) the lowest output: input ratio.

Table 32. Total labour input (hrs/ha/yr) for different crops grown at 1000 to 1500 m asl without integration of trees (control).

Season	Crop components	Human labour				Bullock labour
		Man	Woman	Child	Total	
Winter	MCC-1	224.5	542.6	194.4	961.6	130.8
	Wheat	136.00	541.4	-	677.4	113.3
	MCC-2	111.2	672.7	-	783.9	97.8
	Barley	112.4	436.0	74.7	623.0	100.2
	Onion (bulb)	291.5	1031.4	402.4	1725.4	91.7
	Potato (tuber)	505.7	553.6	82.5	1141.7	86.3
Summer	Paddy	216.8	631.3	174.8	1022.9	125.9
	MCC-3	253.1	513.1	411.5	1177.6	103.9
	Maize	318.5	508.2	388.9	1215.5	77.8
	Barnyard millet	130.0	452.3	110.0	692.3	130.0
	Finger millet	224.4	327.8	55.6	607.8	124.4
	Soya bean	158.1	353.2	82.1	593.3	76.0

Bund area per ha of cultivated land was 0.028 ha; Bullock = 1 Pair

MCC= Mixed Crop Composition; MCC-1= Wheat + mustard, MCC-2=barley +lentil, and MCC-3= finger millet + black gram + horse gram + cowpea + soya bean

Crop rotation

MCC-1----------------------	Maize----------------------	1 year (Irrigated)
Wheat----------------------	Fallow---------------------	1 year (Rainfed)
MCC-2----------------------	Fallow---------------------	1 year (Rainfed)
Barley---------------------	Fallow---------------------	1year (Rainfed)
Bulb & tubers--------------	Soya bean-----------------	1 year (Irrigated)
Paddy----------------------	Fallow---------------------	1 year (Rainfed)
MCC-3---------------------	Fallow---------------------	1 year (Rainfed)
Barnyard millet------------	Fallow---------------------	1 year (Rainfed)
Finger millet---------------	Fallow---------------------	1 year (Rainfed)

Table 33. Seed rate (kg/ha/yr ±SD) and fertilizer consumption (q/ha/yr ±SD) for different crops grown at 1001 to 1500 m asl without integration of trees (control).

Season	Crop components	Crops	Seed rate	FYM
Winter	MCC-1	Wheat	86.2±6.3	19.6±3.5
		Mustard	3.5±1.0	(1.7±0.2)**
	Mono	Wheat	114.2±6.5	19.3±3.8
	MCC-2	Barley	83.3±5.3	16.6±2.5
		Lentil	13.9±2.5	
	Mono	Barley	100.0±6.3	13.5±2.0
	Mono	Onion	11.5±1.8	22.2±4.5
	Mono	Potato (tuber)	1414.0±40.3*	15.5±2.6
Summer	Mono	Paddy	55.9±5.6	23.3±5.2
	MCC-3	Black gram	6.2±2.0	17.3±4.0
		Horse gram	12.3±3.1	
		Finger millet	3.2±1.0	
		Cow pea	18.5±3.5	
		Soya bean	12.3±3.0	
	Mono	Maize	44.4±5.7	22.2±4.2
	Mono	Barnyard millet	18.0±2.1	14.0±1.5
	Mono	Finger millet	17.5±2.2	14.2±1.8
	Mono	Soya bean	61.5±6.7	14.6±1.5

Crop compositions and crop rotations were same as mentioned in Table 56, *Seed rate fresh weight basis; **fertilizer (Urea)

Yield

Table 34. Crop productivity (q/ha/yr±SD) at 1000 to 1500 m asl in control plots.

Season	Crop components	Crops	Productivity			
			Grain	Husk	Stem	Total crop byproduct
Winter	MCC-1	Wheat	13.4±3.1	3.1±0.8	17.0±4.1	20.0
		Mustard	1.9±0.3	2.1±0.7	4.3±1.1	6.4
	Mono	Wheat	20.2±5.7	5.8±1.4	27.0±5.3	32.9
	MCC-2	Barley	8.3±2.6	1.0±0.2	13.6±2.5	14.7
		Lentil	1.9±0.5	0.7±0.1	1.97±0.2	2.7
	Mono	Barley	11.9±4.7	1.3±0.7	18.0±4.2	19.2
	Mono	Onion (bulb)*	-	-	100.0±10.6	-
	Mono	Potato (tuber)*	-	-	80.0±9.8	-
Summer	Mono	Paddy	16.6±5.3	-	29.7±3.8	29.7
	MCC-3	Black gram	2.7±1.0	2.8±0.9	3.7±0.2	6.5
		Horse gram	2.7±1.0	2.4±1.0	3.7±0.2	6.2
		Finger millet	2.4±0.9	2.1±1.0	5.1±1.0	7.2
		Cow pea	3.4±1.1	1.8±0.6	3.5±0.1	5.3
		Soya bean	2.8±1.0	2.2±10	4.7±1.3	6.9
	Mono	Maize	24.1±5.2	10.4±3.2**	36.9±4.8	47.3
	Mono	Barnyard millet	13.4±3.4	2.62±0.8	30.2±4.9	32.8
	Mono	Finger millet	12.8±3.5	2.7±1.0	32.6±5.6	35.3
	Mono	Soya bean	10.3±4.1	2.7±1.1	9.5±2.1	12.2

Crop compositions and crop rotations were same as mentioned in Table 56, *Fresh weight basis, **Kernal weight

Productivity is a time averaged value. It is not one or two years yield value.

Table 35. Comparative energy budget (Mj/ha/yr) for the different crops grown without integration of trees at 1000 to 1500 m asl.

Season	Crop components	Inputs					Outputs				Net return	Output/ Input ratio
		Human labour	Bullock power	FYM & Fertilizers	Seed	Total inputs	Grain	Dry fodder	Bund grass	Total outputs		
Winter	MCC-1	460.8	792.5	33844.1	1475.8	36573.2	26076.2	36726.6	195.0	62997.8	26424.7	1.7
	Wheat	331.6	686.8	28156.0	1849.49	31023.8	32683.5	45657.3	413.4	78754.2	47730.4	2.5
	MCC-2	377.3	592.4	24331.0	1585.9	26886.5	16662.8	24053.1	421.2	41137.1	14250.5	1.5
	Barley	296.0	607.2	19710.0	1620.0	22233.3	19220.0	26693.6	390.0	46303.6	24070.3	2.1
	Onion	718.9	555.9	32412.0	158.1	33844.9	38992.2	-	187.2	39179.4	5334.5	1.2
	Potato	536.8	522.7	22666.5	5514.6	29240.6	31200.0	-	171.6	31371.6	2131.00	1.1
Summer	Paddy	481.4	762.7	33996.1	906.2	36146.5	26860.0	42992.5	405.6	70258.1	34111.6	1.9
	MCC-3	547.7	629.4	25236.1	890.6	27303.8	23568.8	45052.7	405.6	69027.1	41723.3	2.5
	Maize	575.3	471.3	32441.2	719.9	34207.7	38964.2	68515.4	214.5	107694.1	73486.5	3.2
	Barnyard millet	332.8	787.7	20440.0	291.6	21852.1	21721.0	75525.2	432.9	97679.1	75827.0	4.5
	Finger millet	297.2	754.0	20681.0	283.5	22015.8	20671.2	51225.6	421.2	72318.0	50302.2	3.3
	Soya bean	286.4	460.8	21338.0	1046.2	23131.4	17537.2	16935.8	222.3	34695.3	11563.9	1.5
Average*		**512.7**	**795.8**	**29597.2**	**1500.6**	**32406.3**	**31006.8**	**48153.1**	**411.2**	**79571.1**	**47164.8**	**2.5**

Crop compositions and crop rotations were same as mentioned in Table 56, *based on crop rotation

Table 36. Monitory input and output (Rs/ha/yr) for different crops grown without integration of trees at 1000 to 1500 m asl.

Season	Crop components	Inputs					Outputs				Net return	Output/ Input ratio
		Human labour	Bullock power	FYM & Fertilizers	Seed	Total inputs	Grain	Dry fodder	Bund grass	Total outputs		
Winter	MCC-1	6084	2452	2739	731	12,006	18,425	1746	50	20,221	8215	1.7
	Wheat	4574	2125	1928	913	9540	10,710	1002	106	11,818	2278	1.2
	MCC-2	5177	1833	1667	778	9455	8715	865	108	9688	233	1.0
	Barley	3988	1879	1370	600	7837	7118	960	100	8178	341	1.0
	Onion	10,507	1720	2222	1840	16,289	59,988	-	48	60,036	43,747	3.7
	Potato	8194	1617	1552	7070	18,433	40,000	-	44	40,044	21;611	2.2
Summer	Paddy	6498	2360	2329	336	11,523	9948	1482	104	11,534	11	1.0
	MCC-3	6963	1947	1728	743	11,381	18,357	713	104	19,174	7793	1.7
	Maize	7421	1458	2222	355	11,456	19,242	1842	55	21,139	9683	1.8
	Barnyard millet	4376	2437	1400	90	8303	6704	1508	111	8323	20	1.0
	Finger millet	4221	2333	1470	87	8111	6880	1630	108	8118	7	1.0
	Soya bean	3898	1426	1462	923	7709	15,474	473	57	16,004	8295	2.1
Average*		**6950**	**2435**	**2245**	**1112**	**12,742**	**19,063**	**1358**	**105**	**20,526**	**7784**	**1.6**

Crop compositions and crop rotations were same as mentioned in Table 56, *based on crop rotation

Table 37. Dominance and ecological success of tree species in three agroforestry systems 1000 to 1500 m asl (n=20 number of quadrats in each system)

Plant species	Relative Frequency (%)			Relative Density (%)			Relative Dominance (%)			Important Value Index (IVI)		
	AS	AH	AHS	AS	AH	AHS	AS	AH	AHS	AS	AH	AHS
Fuelwood, fodder & timber trees												
Bauhinia variegata	10.2	-	-	9.2	-	-	6.1	-	-	25.6	-	-
Celtis australis	21.4	-	14.3	20.4	-	13.7	24.4	-	16.2	66.2	-	44.2
Ficus auriculata	10.4	-	3.1	9.2	-	2.5	11.2	-	3.8	30.8	-	9.5
F. cunia	3.1	-	-	3.2	-	-	4.6	-	-	10.9	-	-
Grewia optiva	13.1	-	11.0	14.2	-	12.2	10.9	-	10.5	38.3	-	33.6
Melia azedarach	3.1	-	1.1	3.4	-	1.0	6.2	-	2.3	12.7	-	4.4
Morus alba	8.1	-	8.7	7.7	-	6.6	9.6	-	9.2	25.4	-	24.5
Ougeinia oojeinensis	10.2	-	-	14.7	-	-	14.3	-	-	39.3	-	-
Quercus leucotrichophora	15.2	-	-	11.3	-	-	6.4	-	-	32.9	-	-
Toona ciliata	5.1	-	-	6.7	-	-	6.3	-	-	18.1	-	-
Fruit trees												
Carica papaya	-	8.4	-	-	9.1	-	-	6.1	-	-	23.6	-
Citrus limonia	-	11.2	5.4	-	11.0	4.0	-	5.3	11.7	-	27.4	21.1
C. reticulata	-	13.2	11.3	-	12.6	13.7	-	6.0	4.7	-	31.8	29.7
C. sinensis	-	22.3	12.5	-	25.9	10.9	-	12.4	3.7	-	60.6	27.2
Juglans regia	-	10.0	8.2	-	8.6	9.9	-	31.3	21.3	-	50.0	39.4
Mangifera indica	-	4.2	-	-	2.4	-	-	4.6	-	-	11.3	-
Musa paradisica	-	13.4	-	-	15.5	-	-	23.3	-	-	52.2	-
Prunus armeniaca	-	2.0	1.1	-	1.6	1.9	-	1.2	1.0	-	4.8	4.0
P. persica	-	15.2	10.3	-	13.3	12.5	-	9.8	6.5	-	38.3	29.4
Psidium guajava	-	-	7.1	-	-	6.3	-	-	4.0	-	-	17.3
Pyrus communis	-	-	4.0	-	-	3.0	-	-	3.2	-	-	10.2
P. malus	-	-	2.0	-	-	1.8	-	-	1.9	-	-	5.6

Table 38. Tree productivity in different agroforestry systems at 1000 to 1500 m asl.

Tree Species	Uses	Tree productivity (kg/tree/yr ±SD)	Agroforestry Systems (kg/ha/yr ±SD)		
			AS	AH	AHS
Bauhinia variegata	Fodder	15.5±3.1	222.8±44.6	-	-
	Fuelwood	8.5±2.1	121.2±30.7	-	-
Celtis australis	Fodder	19.3±4.1	614.2±131.6	-	452.9±97.0
	Fuelwood	10.6±2.3	335.7±74.1	-	247.5±54.6
Ficus auriculata	Fodder	11.8±3.4	168.3±48.9	-	51.2±14.9
	Fuelwood	4.7±1.0	66.7±14.3	-	20.3±4.4
F. cunia	Fodder	8.5±2.2	44.5±11.3	-	-
	Fuelwood	4.6±1.1	23.8±5.8	-	-
Grewia optiva	Fodder	12.0±3.2	265.8±71.3	-	250.2±67.1
	Fuelwood	7.8±2.1	171.3±45.3	-	161.3±42.6
	Fibre	0.4±0.1	7.7±2.2	-	7.3±2.1
Melia azedarach	Fodder	15.1±2.5	74.3±12.4	-	24.6±4.1
	Fuelwood	7.3±1.7	36.0±8.2	-	11.9±2.72
	Timber volume (m^3)	0.3±0.1	1.4±0.3	-	0.46±0.11
Morus alba	Fodder	10.7±3.7	128.2±44.6	-	121.1±42.1
	Fuelwood	8.2±2.4	97.9±28.9	-	92.5±27.3
Ougeinia oojeinensis	Fodder	15.2±4.1	348.1±94.2	-	-
	Fuelwood	8.0±2.6	183.4±58.5	-	-
	Timber volume (m^3)	0.2±0.04	4.6±0.9	-	-
Quercus leucotrichophora	Fodder	17.3±4.0	303.6±70.2	-	-
	Fuelwood	8.3±2.0	145.1±35.6	-	-
	Timber volume (m^3)	0.2±0.1	3.9±1.1	-	-
Toona ciliata	Timber volume (m^3)	0.48±0.08	5.0±0.8	-	-
Carica papaya	Fruit	14.2±5.0	-	161.3±57.0	-
Citrus limonia	Fruit	32.9±6.2	-	451.8±85.5	225.6±42.7
C. reticulata	Fruit	30.6±6.7	-	479.2±105.7	715.7±157.9
C. sinensis	Fruit	41.2±5.3	-	1330.7±171.7	766.8±98.9
Juglans regia	Fruit	21.3±7.8	-	229.9±84.2	361.3±132.3
Mangifera indica	Fruit	8.0±2.4	-	24.4±7.4	-
Musa paradisica	Fruit	7.0±2.0	-	135.4±38.7	-
Prunus armeniaca	Fruit	8.0±2.5	-	15.7±4.9	25.9±8.1
P. persica	Fruit	11.0±2.1	-	183.6±35.5	235.5±45.5
Psidium guajava	Fruit	12.7±3.7	-	-	135.6±39.9
Pyrus communis	Fruit	21.0±5.2	-	-	107.3±26.7
P. malus	Fruit	28.00±5.18	-	-	85.4±15.8

Table 38.1. Total productivity (q/ha/yr ±SD) of different agroforestry systems at 1000 to 1500 m asl.

Uses	Control	Agroforestry Systems		
		AS	AH	AHS
Fodder	-	21.7±5.3	-	9.0±2.3
Fuelwood	-	11.8±3.0	-	5.3±1.3
Fibre	-	0.1±0.02	-	0.1±0.02
Timber volume (m^3)	-	14.8±3.1	-	0.5±0.1
Fruit	-	-	30.1±5.9	26.6±5.7
Bund grass	1.1±0.2	1.1±0.2	1.2±0.3	1.1±0.1

Table 39. Total labour input (hrs/ha/yr) for different crops grown in agrisilvicultural agroforestry systems at 1000 to 1500 m asl.

Season	Crop components	Human labour				Bullock labour
		Man	Woman	Child	Total	
Winter	MCC-1	210.4	655.8	182.2	1048.4	122.5
	Wheat	121.8	798.5	-	920.4	106.2
	MCC-2	104.2	921.5	-	1025.7	91.9
	Barley	105.3	699.6	70.0	874.8	93.9
Summer	Paddy	203.1	731.2	163.8	1098.1	118.0
	MCC- 3	237.2	771.9	385.7	1394.7	96.4
	Barnyard millet	121.8	715.0	103.1	939.9	121.8
	Finger millet	210.3	598.3	52.1	860.7	116.6

Bund area per ha of agrisilvicultural agroforestry system was 0.028 ha; Bullock= 1Pair

MCC= Mixed Crop Composition; MCC-1= Wheat + mustard, MCC-2= Barley + lentil, and MCC-3= Finger millet + cow pea + horse gram + soyabean + amaranth

Crop rotation

MCC –1------------------------- Paddy------------------- 1Year (Irrigated)
Wheat---------------------------- Fallow------------------ 1Year (Irrigated)

MCC-2-------------------------- Fallow------------------ 1 year (Rainfed)
Barley--------------------------- Fallow------------------ 1 year (Rainfed)

MCC-3-------------------------- Fallow------------------ 1 year (Rainfed)
Barnyard millet----------------- Fallow------------------ 1 year (Rainfed)

Finger millet-------------------- Fallow------------------ 1 year (Rainfed)

Table 40. Seed rate (kg/ha/yr ±SD) and fertilizer consumption (q/ha/yr ±SD) for different crops grown in agrisilvicultural agroforestry system at 1000 to 1500 m asl.

Season	Crop components	Crops	Seed rate	Fertilizer consumption	
				FYM	Urea
Winter	MCC-1	Wheat	80.8±3.7	18.4±2.2	1.6±0.0
		Mustard	3.2±0.8		
	Mono	Wheat	107.0±6.4	18.1±2.0	-
	MCC-2	Barley	78.1±5.2	15.6±1.8	-
		Lentil	13.0±2.4		
	Mono	Barley	93.8±5.4	12.7±1.6	-
Summer	Mono	Paddy	52.4±6.3	21.9±3.1	-
	MCC-3	Black gram	5.8±1.3	16.3±2.4	-
		Horse gram	11.6±2.5		
		Finger millet	3.0±0.3		
		Cow pea	17.4±4.7		
		Soya bean	11.6±3.0		
	Mono	Barnyard millet	16.9±2.4	13.2±2.0	-
	Mono	Finger millet	16.4±3.0	13.3±2.0	-

Crop compositions and crop rotations were same as mentioned in Table 63

Table 41. Crop productivity (q/ha/yr ±SD) in agrisilvicultural agroforestry system at 1000 to 1500 m asl.

Season	Crop components	Crops	Productivity			
			Grain	Husk	Stem	Total crop byproduct
Winter	MCC-1	Wheat	12.2±2.5	2.8±0.5	15.4±2.2	18.3
		Mustard	1.7±0.3	1.9±0.3	3.9±0.5	5.8
	Mono	Wheat	18.3±3.4	5.3±1.8	24.6±4.2	29.9
	MCC-2	Barley	6.4±1.1	0.7±0.1	8.8±1.4	9.5
		Lentil	1.7±0.3	0.6±0.3	1.8±0.1	2.4
	Mono	Barley	10.1±2.6	2.1±0.9	16.8±2.5	18.8
Summer	Mono	Paddy	12.4±2.7	-	19.9±3.2	19.9
	MCC-3	Black gram	2.5±0.7	2.5±0.7	3.4±0.9	5.9
		Horse gram	2.4±0.4	2.2±0.7	3.4±0.9	5:6
		Finger millet	2.2±0.7	2.0±0.3	4.6±1.0	6.6
		Cow pea	3.1±1.1	1.6±0.3	3.2±0.5	4.8
		Soya bean	2.5±1.0	2.0±0.5	4.3±1.1	6.3
	Mono	Barnyard millet	11.6±2.5	2.4±0.6	28.4±5.2	30.8
	Mono	Finger millet	10.1±2.6	2.5±0.6	25.6±4.7	28.1

Crop compositions and crop rotations were same as mentioned in Table 63

Table 42. Comparative energy budget (Mj/ha/yr) for different crops grown in agrisilvicultural agroforestry system at 1000 to 1500 m asl.

Season	Crop components	Inputs					Outputs						Net return	Output / Input ratio
		Human labour	Bullock power	FYM & Fertilizers	Seed	Total inputs	Grain	Dry fodder	Bund grass	Tree fodder	Fuel wood	Total outputs		
Winter	MCC-1	492.4	742.6	31812.9	1382.0	34429.8	23758.2	33452.7	195.0	4221.2	10402.4	72029.5	37599.7	3.0
	Wheat	426.6	643.6	26466.6	1733.2	29270.0	29774.6	41592.8	405.6	9113.2	23267.0	104153.3	74883.3	3.6
	MCC-2	473.2	556.8	22871.0	1486.2	25387.2	13157.8	16593.7	425.1	9113.2	23267.0	62556.8	37169.6	2.5
	Barley	397.1	569.0	18527.4	1518.8	21012.3	16378.2	26200.0	468.0	9113.2	23267.0	75426.4	54414.1	3.6
Summer	Paddy	505.4	714.8	31956.3	849.4	34025.9	20001.8	28856.6	230.1	4892.0	12864.5	66845.0	32819.1	2.0
	MCC-3	632.9	584.1	23722.0	834.4	25773.4	21235.0	41042.8	390.0	9113.2	23267.0	95048.1	69274.7	3.7
	Barnyard millet	431.6	738.2	19214.0	273.3	20657.0	18744.5	44586.0	444.6	9113.2	23267.0	96155.3	75498.3	4.7
	Finger millet	398.2	706.6	19434.0	265.7	20804.5	16411.1	40706.9	460.2	9113.2	23267.0	89957.5	69153.0	4.3
Average*		**536.8**	**750.8**	**27714.9**	**1191.8**	**30194.3**	**22780.2**	**39004.5**	**431.2**	**9113.2**	**14695.6**	**86024.7**	**55830.7**	**2.9**

Crop compositions and crop rotations were same as mentioned in Table 63, *based on crop rotation.

Table 43. Monitory input and output (Rs/ha/yr) for different crop grown in agrisilvicultural agroforestry system at 1000 to 1500 m asl

Season	Crop compon -ents	Inputs					Outputs						Net return	Output/ Input ratio
		Human labour	Bullock power	FYM & Fertilizers	Seed	Total inputs	Grain	Dry fodder	Bund grass	Tree fodder	Fuel wood	Total outputs		
Winter	MCC-1	6623	2298	2574	684	12,179	11,837	1007	50	2281	798	15,973	3894	1.3
	Wheat	6057	1991	1813	856	10,717	14,703	1496	106	5527	1451	23,281	12,564	2.2
	MCC-2	6671	1723	1566	729	10,689	7191	597	109	5527	1451	14,875	4186	1.4
	Barley	5555	1760	1269	562	9146	6066	942	120	5527	1451	14,106	4960	1.5
Summer	Paddy	6961	2211	2189	314	11,675	7408	995	59	3246	653	12,361	686	1.1
	MCC-3	8345	1807	1625	697	12,474	16,723	649	100	5527	1451	24,450	11,976	2.0
	Barnyard millet	5920	2284	1316	84	9604	5785	1418	114	5527	1451	14,295	4691	1.5
	Finger millet	5774	2186	1331	82	9373	5065	1280	118	5527	1451	13,441	4068	1.4
Average*		**7415**	**2323**	**1955**	**572**	**12,265**	**10,683**	**1198**	**111**	**11,053**	**1451**	**24,496**	**12,231**	**2.0**

Crop compositions and crop rotations were same as mentioned in Table 63, *based on crop rotation

Table 44. Total labour input (hrs/ha/yr) for different crops grown in agrihorticultural agroforestry system at 1000 to 1500 m asl.

Season	Crop components	Human labour				Bullock labour
		Man	Woman	Child	Total	
Winter	Wheat	117.0	668.1	-	785.1	102.0
	MCC-2	100.1	865.3	-	965.4	88.3
Summer	MCC-3	227.7	721.7	370.3	1319.8	92.6
	Barnyard millet	120.0	667.0	99.0	886.0	120.0
	Finger millet	202.0	554.0	49.5	805.5	112.0
	Paddy	195.1	639.2	157.4	991.7	113.3

Bund area per ha of agrihorticultural agroforestry system was 0.029 ha; Bullock =1Pair

MCC= Mixed Crop Composition; MCC-2= Barley + lentil, and MCC-3= Black gram + Horse gram + Finger millet + cow pea + soya bean

Crop rotation

Wheat-------------------------------	Paddy-------------------------	1 year
MCC–2-------------------------------	Fallow------------------------	1 year
MCC-3-------------------------------	Fallow------------------------	1 year
Barnyard millet--------------------	Fallow------------------------	1 year
Finger millet----------------------	Fallow------------------------	1 year

Table 45. Seed rate input (kg/ ha/yr ±SD) and fertilizer consumption (q/ha/yr ±SD) for different crops grown in agrihorticultural agroforestry system at 1000 to 1500 m asl.

Season	Crop components	Crops	Seed rate	FYM
Winter	Mono	Wheat	102.7±6.5	16.7±1.5
	MCC-2	Barley	75.0±4.3	19.00±3.1
		Lentil	12.0±2.5	
Summer	MCC-3	Black gram	5.6±1.2	19.5±3.4
		Horse gram	11.1±2.8	
		Finger millet	2.9±0.3	
		Cowpea	16.7±3.1	
		Soya bean	11.1±2.9	
	Mono	Barnyard millet	16.2±3.1	16.6±2.9
	Mono	Finger millet	15.8±3.0	16.7±2.5
	Mono	Paddy	50.4±4.1	22.5±3.8

Crop compositions and crop rotations were same as mentioned in Table 68

Table 46. Crop productivity (q/ha/yr ±SD) in agrihorticultural agroforestry system at 1000 to 1500 m asl.

Season	Crop components	Crops	Productivity			
			Grain	Husk	Stem	Total crop byproduct
Winter	Mono	Wheat	11.1±2.1	2.38±0.8	14.26±2.0	16.6
	MCC-2	Barley	6.00±1.3	0.68±0.1	7.68±1.1	8.4
		Lentil	1.27±0.3	0.54±0. 1	1.17±0.3	1.7
Summer	MCC-3	Black gram	2.13±0.6	2.20±0.8	3.07±1.0	5.3
		Horse gram	2.19±0.5	2.00±0.2	3.05±0.9	5.1
		Finger millet	2.01±0.6	1.33±0.2	4.08±0.8	5.4
		Cowpea	2.82±0.3	1.28±0.1	2.79±0.7	4.1
		Soya bean	2.00±0.5	1.59±0.2	3.81±1.0	5.4
	Mono	Barnyard millet	8.01±2.1	2.06±0.4	16.14±2.7	18.2
	Mono	Finger millet	9.01±2.1	2.08±0.5	18.34±3.0	20.4
	Mono	Paddy	8.23±1.8	-	16.00±2.5	16.0

Crop compositions and crop rotations were same as mentioned in Table 68.

Table 47. Comparative energy budget (Mj/ha/yr) for different crops grown in agrihorticultural agroforestry system at 1000 to 1500 m asl.

Season	Crop components	Inputs					Outputs					Net return	Output/ Input ratio
		Human labour	Bullock power	FYM & Fertilizers	Seed	Total inputs	Grain	Dry fodder	Bund grass	Fruit	Total outputs		
Winter	Wheat	365.5	618.1	24331.0	1664.4	26979.0	17898.3	23129.0	234.0	35764.1	77025.4	50046.4	2.9
	MCC-2	442.8	534.8	27681.6	1427.5	30086.6	11882.0	19002.9	460.2	44953.2	76298.3	46211.6	2.5
Summer	Paddy	461.5	686.4	32831.5	815.7	34795.0	13339.1	23207.3	218.4	9189.1	45953.8	11158.8	1.3
	MCC-3	596.2	561.0	28499.2	801.3	30457.6	18790.3	35339.0	432.9	44953.2	99515.3	69057.7	3.3
	Barnyard millet	425.4	727.1	24182.0	262.4	25597.0	12971.7	26387.7	452.4	44953.2	84765.0	59167.9	3.3
	Finger millet	370.0	678.7	24399.0	255.2	25702.9	14593.0	29616.5	468.0	44953.2	89630.8	63927.9	3.5
Average*		**532.3**	**761.2**	**32384.9**	**1045.3**	**34723.6**	**17894.9**	**31336.5**	**453.2**	**44953.2**	**94637.7**	**59913.5**	**2.7**

Crop compositions and crop rotations were same as mentioned in Table 68, *based on crop rotation

Table 48. Monetary input and output (Rs/ha/yr) for different crops grown in agrihorticultural agroforestry system at 1000 to 1500 m asl

Season	Crop components	Inputs					Outputs					Net return	Output / Input ratio
		Human labour	Bullock power	FYM & Fertilizers	Seed	Total inputs	Grain	Dry fodder	Bund grass	Fruit	Total outputs		
Winter	Wheat	5200	1912	1667	822	9601	8838	832	60	14,472	24,202	14,601	2.5
	MCC-2	6484	1655	1896	700	10,535	6142	504	118	21,922	28,686	18,151	2.7
Summer	Paddy	6272	2124	2249	302	10,947	4940	800	56	7450	13,246	2299	1.2
	MCC-3	7892	1736	1952	669	12,249	14,586	557	111	21,922	37,176	24,927	3.0
	Barnyard millet	5590	2250	1656	81	9577	4004	807	116	21,922	26,849	17,272	2.8
	Finger millet	5415	2100	1671	79	9265	4504	917	120	21,922	27,463	18,198	3.0
Average*		**73331**	**2355**	**2159**	**531**	**12,375**	**8603**	**883**	**116**	**21,922**	**31,524**	**19,149**	**2.6**

Crop compositions and crop rotations were same as mentioned in Table 68, *based on crop rotation

Table 49. Total labour input (hrs/ha/yr) for different crops grown in agrihortisilvicultural agroforestry system at 1000 to 1500 m asl.

Season	Crop components	Crops	Human labour				Bullock labour
			Man	Woman	Child	Total	
Winter	Bulb & tubers (Mono)	Onion	260.9	1167.2	360.2	1788.3	82.1
		Potato	452.6	739.5	73.8	1265.9	77.2
	Leafy vegetables (Mono)	Mustard leaf	-	1288.4	-	1288.4	-
Summer	Mono	Maize	285.1	622.0	348.0	1255.1	69.6
	Summer vegetables (Mono)	Bottle gourd	-	660.9	-	660.9	-
		Brinjal	-	1267.4	-	1267.4	-
		Chilli	-	1370.8	-	1370.8	-
		Cucumber	-	675.5	-	675.5	-
		French bean	-	1070.0	-	1070.0	-
		Ladies finger	-	1222.1	-	1222.1	-
		Pumpkin	-	620.0	-	620.0	-
		Radish	-	790.1	-	790.1	-
		Tomato	-	1379.7	-	1379.7	-
Annual	Rhizome (Mono)	Elephant ear	252.0	684.2	74.5	1010.7	74.5

Bund area per ha of agrihortisilvicultural agroforestry system was 0.028 ha; Bullock= 1 Pair

Crop rotation

Bulb and Tubers----------	Summer vegetables ----------------	1 year
Mustard leaf---------------	Maize----------------------------------	1 year
Rhizome ------------------	--	1 year

Table 50. Seed rate (kg/ha/yr ±SD) and fertilizer consumption (q/ha/yr ±SD) in agrihortisilvicultural agroforestry system at 1000 to 1500 m asl.

Season	Crops	Seed rate	FYM
Winter	Onion	10.3±1.4	21.3±2.5
	Potato (tuber)	1265.0±96.2*	20.0±2.2
	Mustard leaf	14.1±2.7	21.5±3.0
Summer	Maize	39.8±3.5	21.3±3.1
	Bottle gourd	6.7±1.1	11.4±1.3
	Brinjal	0.7±0.1	17.9±2.0
	Chilli	0.9±0.1	19.3±2.1
	Cucumber	3.5±0.8	11.4±1.1
	French bean	35.9±3.4	19.3±1.8
	Ladies finger	17.0±2.1	19.1±2.1
	Pumpkin	6.5±1.0	11.0±1.3
	Radish	9.2±1.2	19.9±3.3
	Tomato	0.7±0.1	21.4±4.0
Annual	Elephant ear	1310.0±81.3*	19.3±3.2

Crop compositions and crop rotations were same as mentioned in table 73
*Seed rate fresh weight basis.

Table 51. Crop productivity (q/ha/yr ±SD) of major crops in agrihortisilvicultural agroforestry system at 1000 to 1500 m asl.

Season	Crops	Productivity
Winter	Onion (bulb)	82.1±5.3
	Potato (tuber)	87.2±5.5
	Mustard leaf	93.2±6.8
Summer	Maize	15.1±2.1 (26.4±2.5)**
	Bottle gourd	108.7±11.6
	Brinjal	76.4±4.8
	Chilli	22.1±2.3*
	Cucumber	59.4±3.4
	French bean	41.7±2.7
	Ladies finger	45.4±2.5
	Pumpkin	98.9±10.0
	Radish	150.8±12.5
	Tomato	73.5±5.7
Annual	Elephant ear	131.5±10.5

Crop compositions and crop rotations were same as mentioned in table 73, *Dry weight basis, **Dry fodder.

Table 52. Comparative energy budget (Mj /ha/yr) for different crops grown in agrihortisilvicultural agroforestry system at 1000 to 1500 m asl.

Season	Crop components	Inputs					Outputs							Net return	Output/ Input ratio
		Human labour	Bullock labour	FYM	Seed	Total inputs	Grain/ Vegetables	*Dry fodder	Bund grass	Tree fodder	Fuel-wood	Fruit	Total outputs		
Winter	Onion	740.5	457.5	31147.7	141.5	32487.2	32034.6	-	214.5	1265.7	26918	30382.9	66589.5	34102.3	2.1
	Potato	577.5	467.8	29194.2	4933.5	35173.0	34000.2	-	202.8	1265.7	26918	30382.9	68543.4	33370.4	2.0
	Mustard leaf	507.6	-	31320.0	325.3	32152.9	26096.0	-	226.2	1265.7	26918	30382.9	60662.6	28509.7	1.9
Summer	Maize	581.5	421.8	31161.2	644.3	32808.8	24462.0	38280.0	218.4	2514.1	6933.8	9291.4	81699.8	48891.0	2.5
	Bottle gourd	261.9	-	16659.0	91.4	17012.4	26088.0	-	234.0	2514.1	6933.8	9291.4	45061.4	28049.0	2.6
	Brinjal	487.2	-	26113.5	9.1	26609.8	18336.0	-	210.6	2514.1	6933.8	9291.4	37286.0	10676.2	1.4
	Chilli	525.3	-	28233.6	11.7	28770.5	30387.5	-	222.3	2514.1	6933.8	9291.4	49349.2	20578.6	1.7
	Cucumber	269.1	-	16701.2	48.1	17018.5	14256.0	-	249.6	2514.1	6933.8	9291.4	33245.0	16226.5	2.0
	French bean	419.5	-	28229.5	609.5	29258.5	70890.0	-	191.1	2514.1	6933.8	9291.4	89820.5	60562.0	3.1
	Ladies finger	479.3	-	27938.7	233.8	28651.8	10905.6	-	245.7	2514.1	6933.8	9291.4	29890.7	1238.9	1.0
	Pumpkin	246.3	-	16113.4	88.7	16448.5	23736.0	-	202.8	2514.1	6933.8	9291.4	42678.2	26229.7	2.6
	Radish	314.4	-	29033.1	212.2	29559.8	36192.0	-	273.0	2514.1	6933.8	9291.4	55204.4	25644.6	1.9
	Tomato	530.6	-	31301.0	9.8	31841.3	17640.0	-	171.6	2514.1	6933.8	9291.4	36551.0	4709.6	1.2
Annual	Elephant ear	445.9	451.2	28181.4	3668.0	32746.6	36820.0	-	440.7	3780.0	9625.6	39674.4	90340.7	57594.1	2.8
Average*		**862.2**	**445.2**	**48438.0**	**2240.4**	**51985.8**	**49333.0**	**12760.0**	**438.8**	**3780.0**	**9625.6**	**39674.4**	**115611.7**	**63625.9**	**2.2**

Crop compositions and crop rotations were same as mentioned in Table 73, *based on crop rotation

Table 53. Monetary input and output (Rs/ha/yr) of agrihortisilvicultural agroforestry system at 1000 to 1500 m asl.

Season	Crop compone-nts	Inputs					Outputs							Net return	Output/ Input ratio
		Human labour	Bullock labour	FYM	Seed	Total inputs	Grain/ Vegeta -bles	Dry fodder	Bund grass	Tree fodder	Fuel wood	Fruit	Total outputs		
Winter	Onion	10,928	1539	2133	1646	16,246	41,070	-	55	904	390	12,055	54,474	38,228	3.4
	Potato	8859	1447	2000	6325	18,631	43,590	-	52	904	390	12,055	56,991	38,360	3.1
	Mustard leaf	8052	-	2145	254	10,451	18,640	-	58	904	390	12,055	32,047	21,596	3.1
Summer	Maize	8556	1305	2134	318	12,312	12,080	1320	56	1521	353	8534	23,864	11,551	1.9
	Bottle gourd	4130	-	1141	532	5803	43,480	-	60	1521	353	8534	53,948	48,145	9.3
	Brinjal	7921	-	1788	231	9940	38,200	-	54	1521	353	8534	48,662	38,722	4.9
	Chilli	8567	-	1934	144	10,645	35,360	-	57	1521	353	8534	45,825	35,180	4.3
	Cucumber	4222	-	1144	350	5716	29,700	-	64	1521	353	8534	40,171	34,455	7.1
	French bean	.6687	-	1933	869	9516	20,850	-	49	1521	353	8534	31,301	21,791	3.3
	Ladies finger	7638	-	1914	850	10,402	27,264	-	63	1521	353	8534	37,735	27,364	3.6
	Pumpkin	3875	-	1104	516	5495	39,560	-	52	1521	353	8534	50,020	44,525	9.2
	Radish	4938	-	1988	184	7110	60,320	-	70	1521	353	8534	70,798	63,688	10.0
	Tomato	8623	-	2144	263	11,030	44,100	-	44	1521	353	8534	54,552	43,522	4.9
Annual	Elephant ear	6760	1396	1930	5240	15,326	52,600	-	113	2425	743	20,589	76,470	61,144	5.0
Average*		**13,183**	**1398**	**3317**	**3413**	**21,311**	**54,333**	**440**	**112**	**2425**	**743**	**20,589**	**78,642**	**57,337**	**3.7**

Crop compositions and crop rotations were same as mentioned in Table 73, *based on crop rotation

Table 54. Comparative energy input and output (Mj/ha/yr) patterns for different crops grown in control and agroforestry systems at 1000 to 1500 m asl.

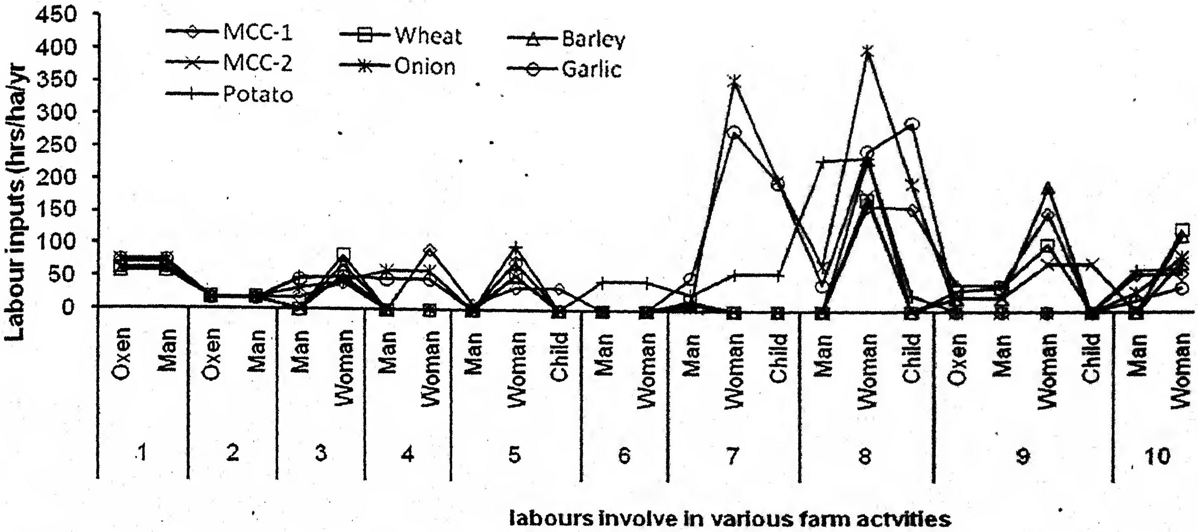
Parameters	Energy			
	Control	AS	AH	AHS
Inputs				
Human labour	512.7 (1.6%)	536.8 (1.8%)	532.3 (1.5%)	862.2 (1.7%)
Bullock labour	795.8 (2.5%)	750.8 (2.5%)	761.2 (2.2%)	445.2 (0.9%)
FYM & fertilizers	29597.2 (91.1%)	27714.9 (91.8%)	32384.9 (93.3%)	48438.0 (93.2%)
Seed	1500.6 (4.6%)	1191.8 (3.9%)	1045.3 (3.0%)	2240.4 (4.3%)
Total inputs	**32406.3**	**30194.3**	**34723.6**	**51985.8**
Outputs				
Grain/ vegetables yield	31006.8 (39.0%)	22780.2 (26.5%)	17894.9 (18.9%)	49333.0 (42.7%)
Crop residue	48153.1 (60.5%)	39004.5 (45.3%)	31336.5 (33.11%)	12760.0 (11.0%)
Fodder from weed & grasses of the bunds	411.2 (0.5%)	431.2 (0.5%)	453.2 (0.48%)	438.8 (0.4%)
Fodder from agroforestry trees	-	9113.2 (10.6%)	-	3780.0 (3.3%)
Fuelwood from agroforestry trees	-	14695.6 (17.1%)	-	9625.6 (8.3%)
Fruit from agroforestry trees	-	-	44953.2 (47.5%)	39674.4 (34.3%)
Total outputs	**79571.1**	**86024.7**	**94637.7**	**115611.7**
Output/ Input ratio				
Grain/vegetables	1.0	0.8	0.5	1.0
Grain/ vegetables + Crop residue	2.4	2.0	1.4	1.2
Grain/ vegetables + Crop residue + Bund grass	2.5	2.1	1.4	1.2
Grain + Crop residue + Bund grass + Fruit	-	-	2.7	-
Grain/ vegetables + Crop residue + Bund grass + Tree fodder	-	2.4	-	1.3
Grain/ vegetables + Crop residue + Bund grass + Tree fodder + Fuelwood	-	2.9	-	1.5
Grain/ vegetables + Crop residue + Bund grass + Tree fodder + Fuelwood + Fruit	-	-	-	2.2

Values in parenthesis represent per cent contribution to total energy input and output of the respective parameters.

Table 55. Comparative monetary (Rs/ha/yr) input and output patterns for different crops grown in control and agroforestry systems at 1000 to 1500 m asl.

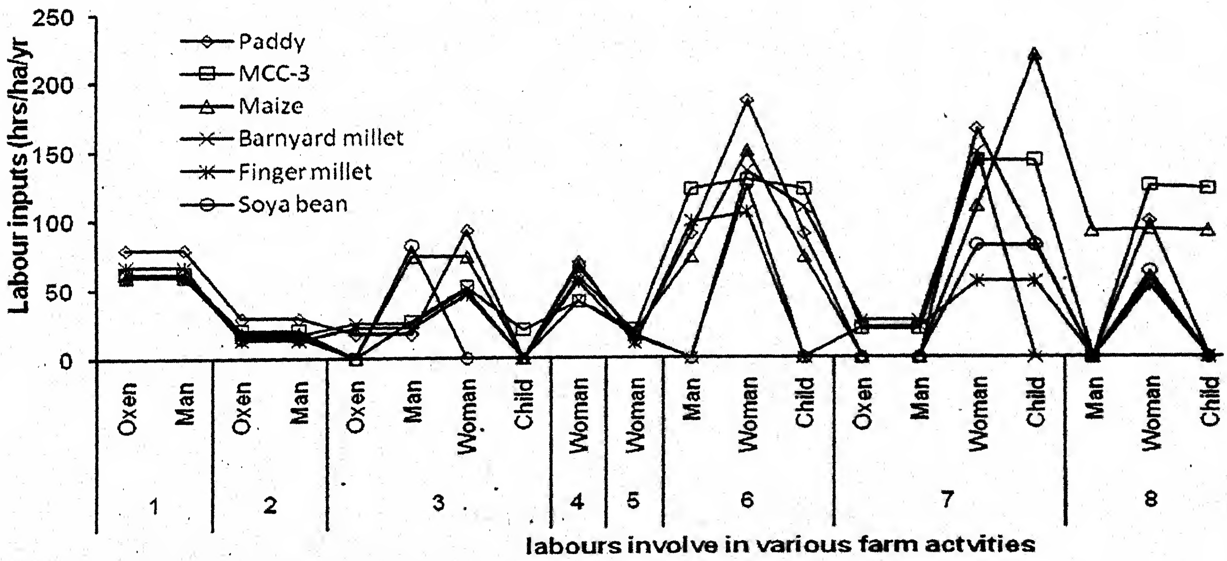
Parameters	Monetory			
	Control	AS	AH	AHS
Inputs				
Human labour	6950.0 (54.5%)	7415.0 (60.5%)	7331.0 (59.2%)	13,183.0 (61.9%)
Bullock labour	2435.0 (19.1%)	2323.0 (18.9%)	2355.0 (19.0%)	1398.0 (6.6%)
FYM & Fertilizers	2245.0 (17.6%)	1955.0 (15.9%)	2159.0 (17.5%)	3317.0 (15.6%)
Seed	1112.0 (8.7%)	572.0 (4.7%)	531.0 (4.3%)	3413.0 (16.0%)
Total inputs	**12,742.0**	**12,265.0**	**12,375.0**	**21,311.0**
Outputs				
Grain/ vegetables yield	19,063.0 (92.9%)	10,683.0 (56.3%)	8603.0 (27.3%)	54,333.0 (69.1%)
Crop residue	1358.0 (6.6)	1198.0 (6.3%)	883.0 (2.8%)	440.0 (0.6%)
Fodder from weed & grasses of the bunds	105.0 (0.5%)	111.0 (0.6%)	116.0 (0.4%)	112.0 (0.1%)
Fodder from agroforestry trees	-	5527.0 (29.1%)	-	4850.0 (3.1%)
Fuelwood from agroforestry trees	-	1451.0 (7.7%)	-	743.0 (0.9%)
Fruit from agroforestry trees	-	-	21,922.0 (69.5%)	20,589.0 (26.2%)
Total outputs	**20,526.0**	**18,970.0**	**31,524.0**	**78,642.0**
Output/ Input ratio				
Grain/vegetables	1.5	0.9	0.7	2.6
Grain/vegetables + Crop residue	1.6	1.0	0.8	2.6
Grain/vegetables + Crop residue + Bund grass	1.6	1.0	0.8	2.6
Grain + Crop residue + Bund grass + Fruit	-	-	2.6	-
Grain/vegetables + Crop residue + Bund grass + Tree fodder	-	1.4	-	2.7
Grain/vegetables + Crop residue + Bund grass + Tree fodder + Fuelwood	-	1.6	-	2.7
Grain/vegetables + Crop residue + Bund grass + Tree fodder + Fuelwood + Fruit	-	-	-	3.7

Values in parenthesis represent per cent contribution to total monetary input and output of the respective parameters



1. Ploughing; 2. Leveling; 3. Hoeing/weeding; 4. Irrigation; 5. Manuring; 6. Bunding; 7. Sowing/transplanting; 8. Harvesting ; 9. Threshing & winnowing; 10. Transportation.

Fig.13. Details of the activities labour input (hrs/ha/yr) of cultivated land without integration of trees for various winter agricultural activities at 1000 to 1500 m asl.



1. Ploughing; 2. Leveling; 3. Hoeing/weeding; 4. Manuring; 5. Sowing/transplanting; 6. Harvesting ; 7. Threshing & winnowing; 8. Transportation.

Fig. 14. Details of the activities labour input (hrs/ha/yr) of cultivated land without integration of trees for various summer agricultural activities at 1000 to 1500 m asl.

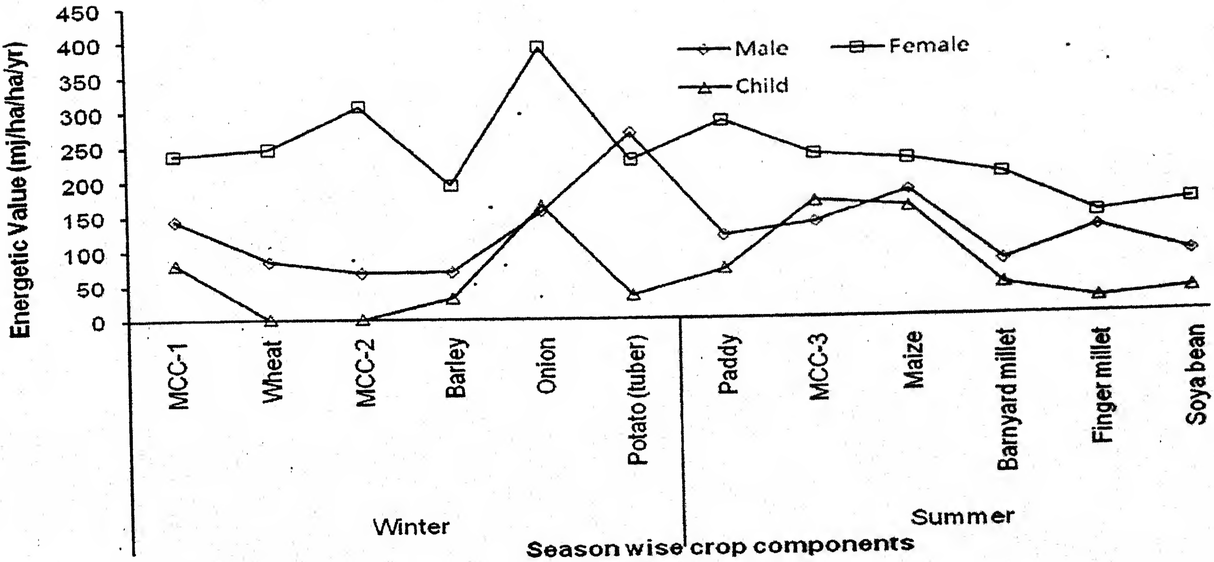
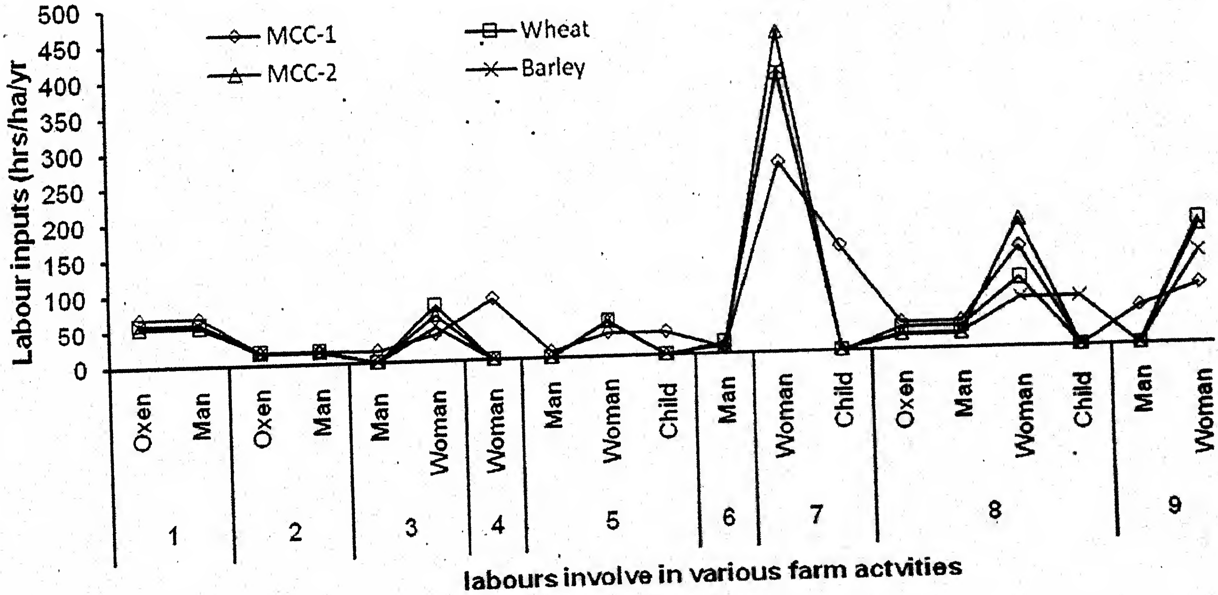
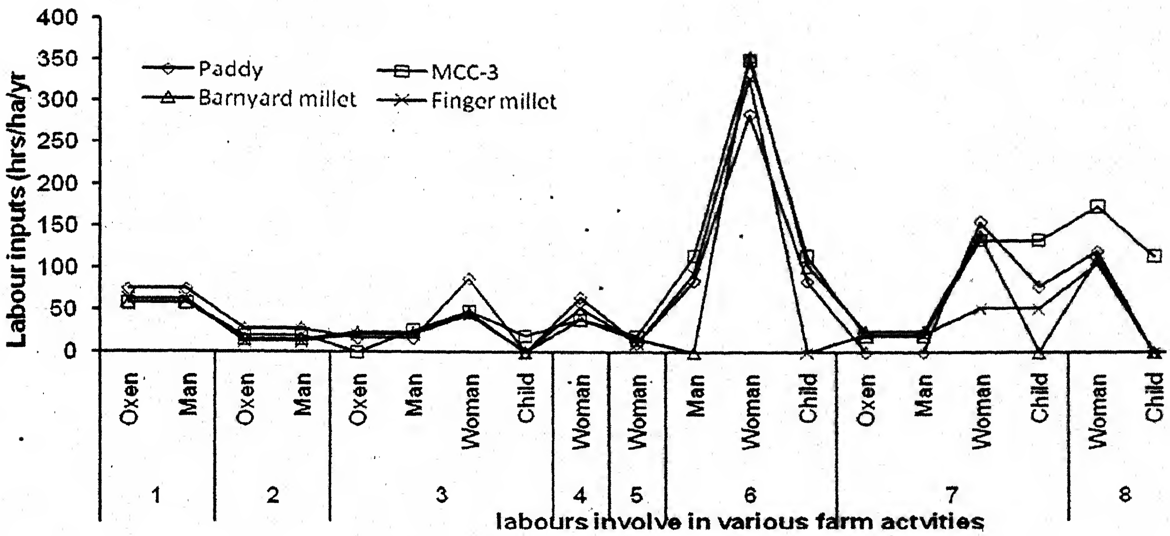


Fig. 15. Category wise energetic value (Mj/hr/ha/yr) of different crop components of without integration of trees at 1000 to 1500 m asl.



1. Ploughing; 2. Leveling; 3. Hoeing/weeding; 4. Irrigation; 5. Manuring;
6. Sowing/transplanting; 7. Harvesting ; 8. Threshing & winnowing; 9. Transportation.

Fig. 16. Details of the activities labour input (hrs/ha/yr) of agrisilvicultural agroforestry system for various winter agricultural activities at 1000 to 1500 m asl.



1. Ploughing; 2. Leveling; 3. Hoeing/weeding; 4. Manuring; 5. Sowing/transplanting; 6. Harvesting ; 7. Threshing & winnowing; 8. Transportation.

Fig. 17. Details of the activities labour input (hrs/ha/yr) of agrisilvicultural agroforestry system for various summer agricultural activities at 1000 to 1500 m asl.

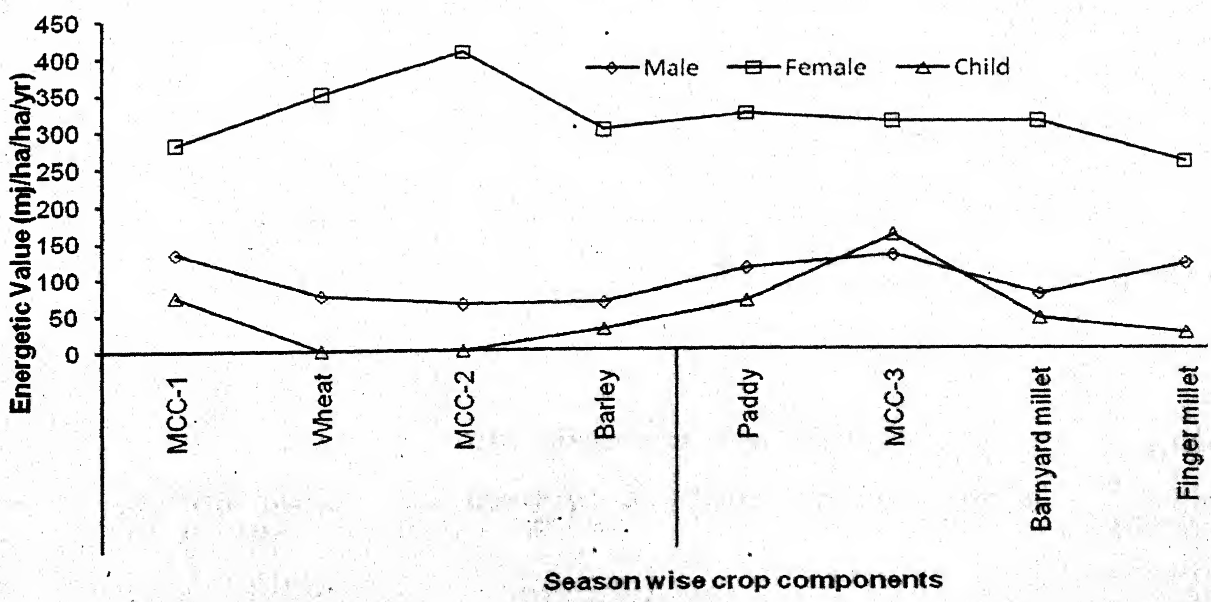
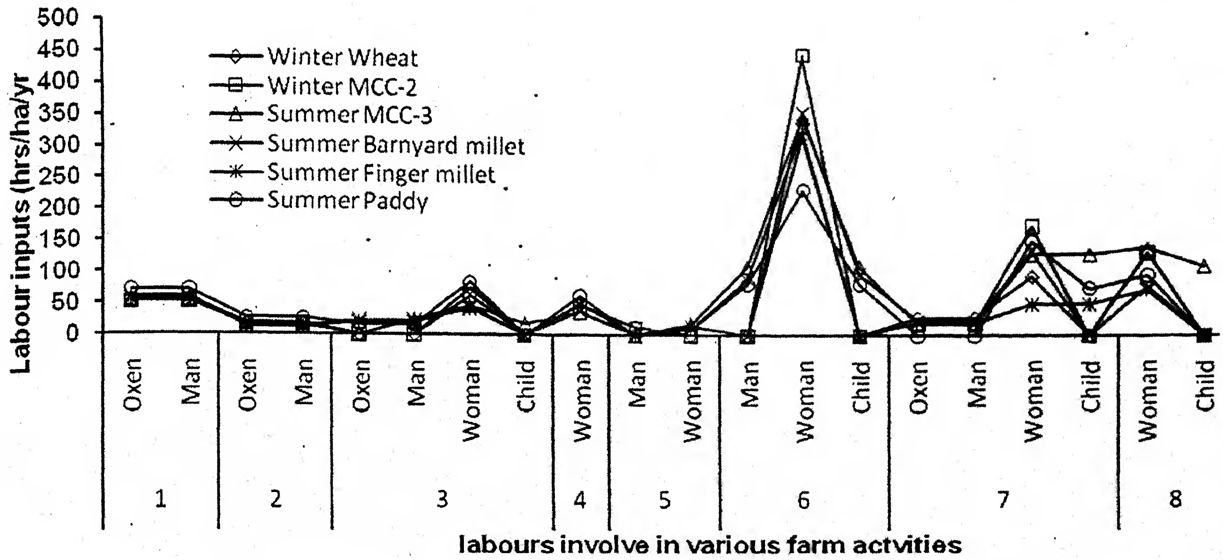


Fig.18. Category wise energetic value (Mj/hr/ha/yr) of different crop components of agrisilvicultural agroforestry system at 1000 to 1500 m asl.



1. Ploughing; 2. Leveling; 3. Hoeing/weeding; 4. Manuring; 5. Sowing/transplanting; 6. Harvesting ; 7. Threshing & winnowing; 8. Transportation.

Fig.19. Details of the activities labour input (hrs/ha/yr) of agrihorticultural agroforestry system for various winter and summer agricultural activities at 1000 to 1500 m asl.

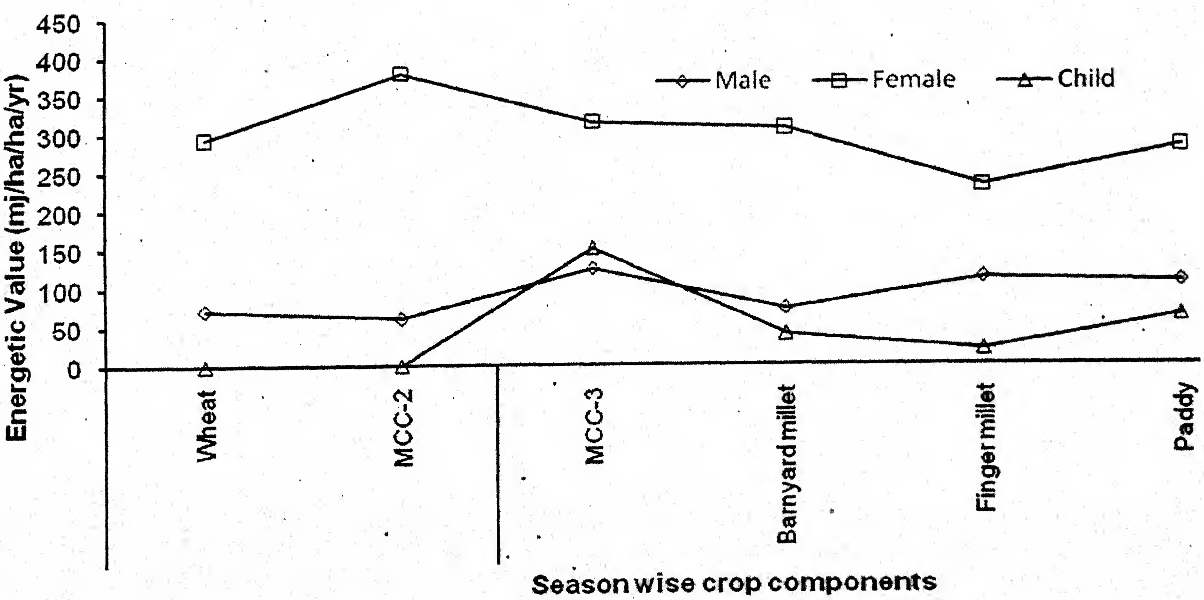
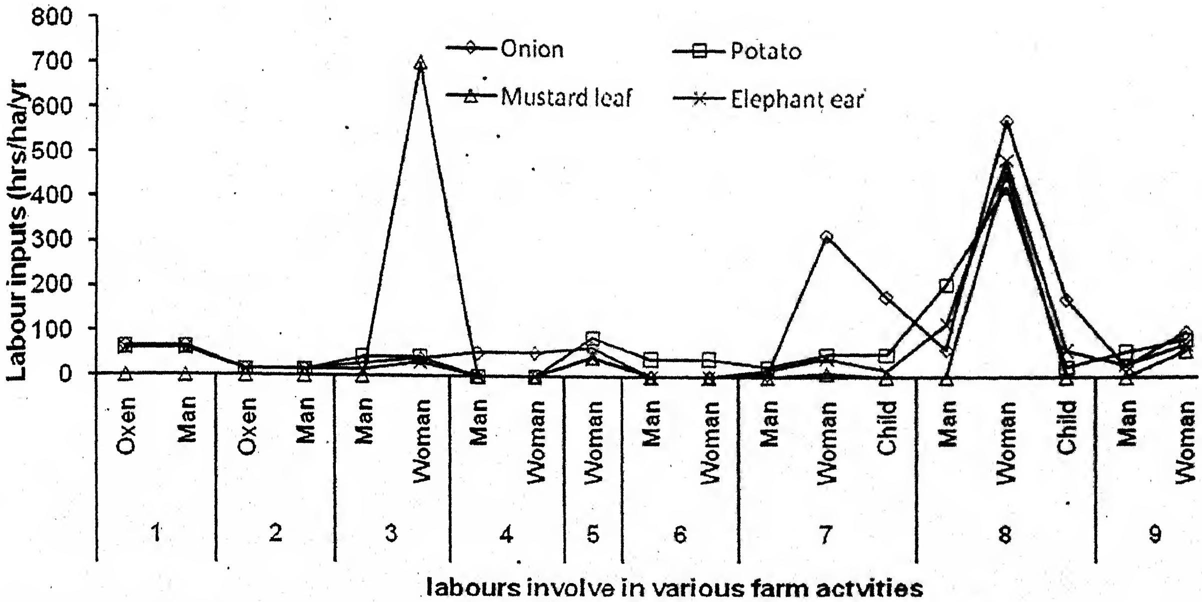


Fig. 20. Category wise energetic value (Mj/hr/ha/yr) of different crop components of agrihoticultural agroforestry system at 1000 to 1500 m asl.



1. Ploughing; 2. Leveling; 3. Hoeing/weeding; 4. Irrigation; 5. Manuring; 6. Bunding; 7. Sowing/transplanting; 8. Harvesting ; 9. Transportation.

Fig. 21. Details of the activities labour input (hrs/ha/yr) of agrihortisilvicultural agroforestry system for various winter and annual crops at 1000 to 1500 m asl

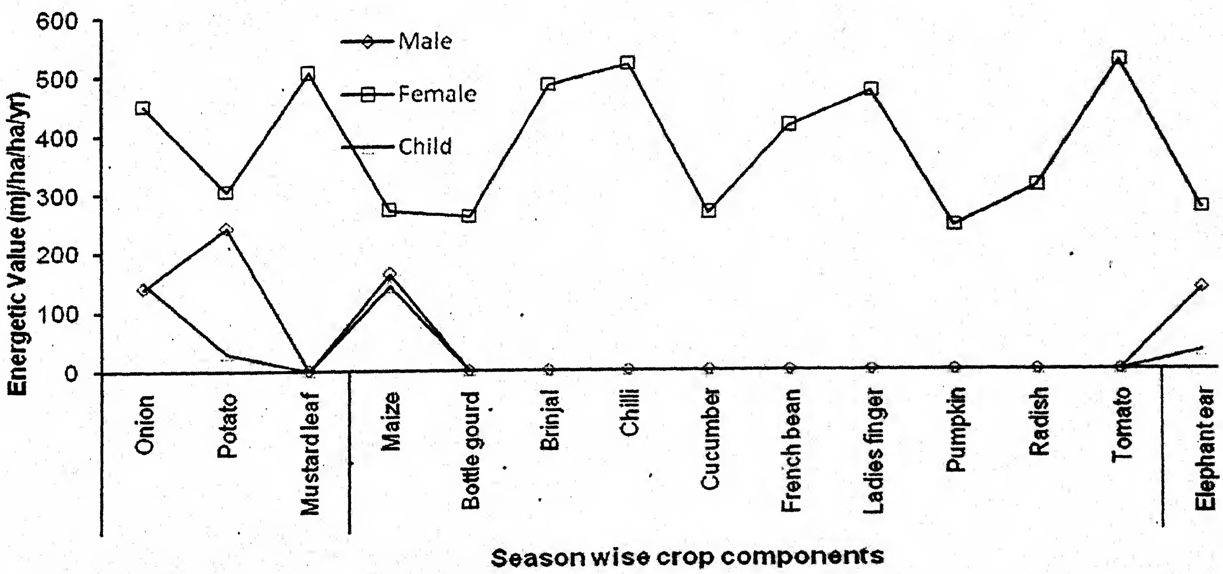


Fig. 22. Category wise energetic value (Mj/hr/ha/yr) of different crop components of agrihotisilvicultural agroforestry system at 1000 to 1500 m asl.

2000 to 2500 m altitude

Table 56 to 60 represents the different cropping patterns, crop combinations, eco-energetic analysis and cost-benefit analysis at 2000 to 2500 m altitude in control plots, *i.e.*, without integrated of trees. On an average, two different crops were grown as winter crops and seven nos. of crops during summer. Wheat and barley were the major winter cereal crops, whereas maize, finger millet, amaranth, buckwheat and potato were the major summer crops. All the crops were cultivated as a mono crop.

Total human labour input (hrs/ha/yr) was recorded highest (1196.5) for maize cultivation, followed by potato (1191.0). Among various crops, minimum human labour input was required for mustard cultivation (621.5 hrs/ha/yr). The bullock labour requirement was highest (112.0 hrs/ha) in finger millet cultivation, followed by barley (102.4 hrs/ha). On an average, 778.6 and 908.4 hrs of human labour was required for per hectare cultivation during winter and summer crops, respectively, irrespective of crops. Females contributed, respectively, 79.7 and 58.8% of the total labour during winter and summer crops. On an average, male contributed 14.2 and 7.2% of the total human labour input to winter and summer crops' cultivation. The bullock labour was required only 98.8 and 77.3 hrs/ha/yr, respectively, for winter and summer crops. All the crops were grown only in rainfed agriculture and the land was left fellow after cultivation of summer crops (**Table 56**).

Ploughing and leveling operations during winter cropping was conducted by male labour. They also contributed labour for hoeing/weeding, manuring, sowing, harvesting, threshing and winnowing, and transportation. Bullock labour was mainly used for ploughing, leveling and threshing. Similarly, during summer cropping, male labour was engaged for ploughing, leveling, hoeing/weeding (particularly in finger millets cultivation), threshing and transportation of the grains. Females contributed for majority of the agricultural operations.

Seed rate input of various agricultural crops has been given in **Table 57**. Potato crop had highest seed (tuber) input rate (1450.0 kg/ha) compared to cereals/pulses/oilseed crops. On an average, the major crops like wheat, barley, maize, finger millet, amaranth, buck wheat, mustard and kidney bean, respectively, had the seed rate of 117.4, 85.7, 50.0, 16.7, 4.5, 66.7, 8.3 and 62.5

kg/ha. The range of FYM application varied from 10.8 (for mustard) to 20.8 q/ha (for kidney bean). Farmers used higher amount of FYM (17.5 to 20.6 q/ha) for cultivation of wheat, barley, maize and potato; and the amount was reduced almost by 30-40% in case of summer crop's cultivation.

Crop productivity (q/ha) has been shown in **Table 58**. On an average, the productivity of wheat was recorded to be 16.5 q/ha. Potato showed the average tuber yield of 116.8 q/ha. Maize yield was recorded to be 20.1 q/ha. The productivity of staple food crops like barley, finger millet, amaranth, buck wheat, mustard and kidney bean was recorded to be 14.1, 14.4, 4.7, 8.3, 4.5 and 15.6 q/ha. The crop byproduct of all the aforesaid crops has been used as a fodder for cattle. The crop byproduct yield was, respectively, 23.6, 20.5, 38.2, 23.5, 16.7 and 12.4 q/ha for wheat, barley, maize, finger millet, buckwheat and kidney bean.

Total energy input (MJ/ha/yr) of human labour for various agricultural operations showed a range of 302.6 (mustard cultivation) to 546.1 (maize cultivation). The human energy consumption was also found comparatively low for kidney bean and potato cultivation (range 512.6–524.5 MJ/ha/yr). Most of the agricultural operations belonged to heavy works. Mono cropping did not exhibit marked variation in total energy requirement of human labour.

Comparative energy budget for various agricultural crops has been shown in **Table 59**. Among various inputs, it has been observed that more than 90% energy input was contributed by FYM, irrespective of crops. The annual energy input (MJ/ha/yr) of human labour, bullock labour and seed was, respectively, 540.2, 639.2 and 1776.0, irrespective of crops. On the other hand, the energy output was, respectively, 41.9, 57.5 and 0.63% through grain/vegetable yield, crop byproduct and fodder from weed and grasses of the bunds. Among various winter and summer crops, total energy input was recorded highest (36725.3 MJ/ha/yr) for potato cultivation, followed by kidney bean (32565.7 MJ/ha/yr) and lowest energy input was recorded for mustard cultivation (16643.4 MJ/ha/yr). The total energy output for winter and summer crops, however, was recorded highest for maize cultivation (88066.5 MJ/ha/yr), followed by amaranth cultivation (83657.4 MJ/ha/yr) and lowest energy output was recorded for mustard cultivation (29538.7 MJ/ha/yr). Among various winter and summer crops, energy

output: input ratio was recorded highest (3.3) to amaranth cultivation, followed by maize (3.2). Lowest output: input ratio, however, was recorded to potato cultivation (1.3).

The total monetary input has been worked out as Rs. 13,044/ha. On an average, the monetary input was highest (56.8% for the total input) through human labour. Bullock labour, FYM and seed, respectively, showed 15.2, 16.4 and 11.6% of the total monetary inputs. Total monetary output was recorded as Rs. 24,981/ha. Inter-comparing the monetary input and output during different cropping seasons, it has been recorded that the monetary input was, respectively, 9,403 and 10,358 Rs/ha to winter and summer crops with the monetary output of Rs. 11,986 and 21,628/ha, accordingly during the same seasons. Among various winter and summer crops, potato cultivation exhibited highest output: input ratio (3.5), followed by kidney bean (2.9) and lowest output: input ratio was observed in finger millet cultivation (1.0) (**Table 60**).

Table 61 depicts the data on phytosociological parameters such as relative frequency, relative density, relative dominance and IVI of different fruit tree-crops found in AH agroforestry system. *Pyrus malus* exhibited highest values of relative frequency, relative density and relative dominance, which has resulted to have highest IVI. A lowest value of relative frequency and relative density, however, was observed in *Prunus domestica*, which influenced to bear lowest IVI in AH system. Although, due to the lowest relative dominance in the *Prunus persica*, it did not have much influence on IVI value.

At this altitude, only AH system was practiced. As many as six fruit tree species were cultivated by the farmers in or around agricultural fields in rainfed situation. The total fruit yield was recorded to be 58.4 q/ha, irrespective of species. Fruit yield was recorded highest in *P. malus* (66.2 kg/tree/yr), followed by *Pyrus communis* (62.0 kg/tree/yr). Lowest fruit production per tree was noticed in *Prunus persica* (6.9 kg/tree/yr).

On an average, 117 nos. of trees were cultivated per ha of land in AH system. Inter-comparing the tree density of fruit trees at species level, maximum density was noticed for *P. malus* (56.8), followed by *P. communis* (23.6) whereas, lowest tree density was recorded for *P. domestica* (6.5). The

productivity of the grass from bunds of agricultural fields was estimated to be 1.2. q/ha/yr (**Table 62**).

Table 63 to 67 represents the different cropping patterns, crop combinations, eco-energetic analysis and cost-benefit analysis of AH system. Out of total cultivated area, *i.e.*, 26.0 ha, AH system was practiced over, 18.2% area. Compared to control, seasonal vegetables were mainly cultivated in this system.

On an average, two different crops were grown as winter crops and eight nos. of crops during summer. Wheat and barley were the major winter cereal crops whereas; maize, finger millet, buckwheat, potato and seasonal vegetables were the major summer crops. Total human labour (hrs/ha) was recorded highest (1446.6) for potato cultivation, followed by maize (1209.9). Among various crop combinations, minimum human labour input was required for pumpkin cultivation (774.7 hrs/ha). The bullock labour (hrs/ha) was required highest (104.5) in finger millet cultivation, followed by barley (95.5). On an average, 968.1 and 1022.2 hrs of human labour was required for per ha cultivation during winter and summer crops, respectively, irrespective of crops in AH system. Females contributed, respectively, 84.8 and 80.5% of the total human labour during winter and summer crops. The bullock labour was required only 92.1 and 30.5 hrs/ha for winter and summer crops (**Table 63**).

Ploughing and leveling operation during winter and summer cropping were exclusively conducted by the males. They also contributed labour for hoeing/weeding, manuring, sowing/transplanting, harvesting, fruit picking, threshing and winnowing, and transportation. Bullock labour was mainly used for ploughing and leveling. However, it was also employed for threshing of wheat, barley and finger millet.

Seed rate input of various agricultural crops has been given in **Table 64**. Potato crop had highest seed (tuber) rate (1352.8 kg/ha) compared to cereal/pulses/oilseed/vegetable crops. On an average, the seed rate for wheat, barley, maize, finger millet, buckwheat, mustard leaf, pumpkin, bottle gourd and cucumber was, respectively, 109.5, 80.0, 46.6, 15.5, 62.2, 14.0, 6.4, 6.1 and 2.8 kg/ha. The range of FYM application varied from 17.1 (for maize) to 24.7 q/ha

(for potato). FYM was also used in fruit trees @ 3.0 kg/tree with highest in *Pyrus malus* (3.7q/ha) and lowest (0.2 q/ha) in *Prunus domestica*.

Crop productivity (q/ha) in AH system has been shown in **table 65**. The average wheat productivity was 14.9 q/ha. Potato showed the average tuber yield of 105.1 q/ha. The grain productivity of staple food crops like barley, maize, finger millet and buckwheat was recorded to be 12.7, 18.1, 8.6 and 7.4 q/ha, respectively. Productivity of important vegetables like mustard leaf, pumpkin, bottle gourd and cucumber was, respectively, 82.1, 85.3, 75.4 and 48.7 q/ha. The crop byproduct yield was, respectively, 21.2, 18.5, 34.3, 17.5 and 15.0 q/ha for wheat, barley, maize, finger millet and buckwheat.

Total energy input (MJ/ha/yr) of human labour for various agricultural operations showed a range of 305.9 (pumpkin cultivation) to 622.5 (potato cultivation). Most of the agricultural operations belonged to heavy works. Mono cropping and mixed cropping did not exhibit marked variation in total energy requirement of human labour.

Comparative energy budget for various agricultural crops has been shown in **table 66**. The annual energy input of human labour, bullock labour and seed was, respectively, 627.5, 591.7 and 1792.2 MJ/ha/yr, however, FYM alone contributed > 90% energy input, irrespective of crops. The energy output was, respectively, 20.3, 24.0, 0.32 and 55.4% through grain/vegetables, crop byproduct, fodder from weed and grasses of the bunds, and fruits. Among various winter and summer crops, total energy input was recorded highest (42470.5 MJ/ha/yr) for potato cultivation, followed by wheat (33842.2 MJ/ha/yr). Highest energy output was recorded for wheat cultivation (131745.1 MJ/ha/yr), followed by finger millet (127102.6 MJ/ha/yr) and lowest in mustard leaf (32581.5 MJ/ha/yr). Energy output: input ratio was recorded highest to finger millet (4.6), followed by buckwheat (4.0). Lowest value of output: input ratio was recorded in mustard leaf cultivation (1.0).

The monetary input and output for AH system has been depicted in **table 67**. Based on crop rotations, the total monetary input has been worked out as Rs. 14,999/ha. On an average, the monetary input was highest (60.1% for the total input) through human labour. Bullock labour, FYM and seed, respectively, contributed 12.1, 18.0 and 9.8% to the total monetary inputs. So far total

monetary output was concerned, it has been recorded as Rs. 57,060/ha, and 31.6% of the total output was achieved through grain/vegetables. Interestingly, 66.8% of the total monetary output was obtained through fruits. Inter-comparing the monetary input and output during different cropping seasons, it has been recorded that the monetary input was, respectively, 10,717 and 10,142 Rs/ha to winter and summer crops with the net monetary output of Rs. 42,948 and 54,914/ha. The monetary output: input ratio was 4.0 and 5.9, respectively, to winter and summer crops. Among various winter and summer crops, pumpkin cultivation exhibited highest output: input ratio (9.9), followed by bottle gourd (9.4) and cucumber (8.8). Lowest output: input ratio was recorded for maize cultivation (2.1).

Table 68 depicts the data on comparative energy budget of AH system including control. On an average, the energy input was > 90% through FYM, and rest was shared by seed, human and bullock labour. Inter-comparing the values between control and AH system, no significant variations have been recorded, however, the total energy input was highest (42351.2 MJ/ha/yr) for AH system and lowest (37265.2 MJ/ha/yr) for control, respectively. So far outputs were concerned, grain/vegetable yield contributed 20.3% in AH system compared to 41.9% in control. Output through crop residue was also recorded highest in control (57.5%) and lowest (24.0%) in AH system. The fruit yield partitioned 55.4% of the total energy output in AH system. The total energy output, however, was recorded highest to AH system (157397.6 MJ/ha/yr) and lowest (71272.9 MJ/ha/yr) to control. The output: input ratio has also been worked out keeping in view the different crops and byproducts and it was 2.1 in control as against of 3.7 in AH system.

Table 69 depicts the data on monetary budget of AH system including control. On an average, the monetary input was > 56% through human labour and rest was shared by bullock labour, FYM and seed. Inter-comparing the values between control and AH system, no significant variations have been recorded, however, the values of total monetary input ranged from 13,044 to 14,999 Rs/ha/yr. Monetary output was recorded to be Rs. 24,981 and Rs. 57,060 in control and AH system, respectively. Grain/vegetable production contributed highest (96.1% of the total output) in control and lowest (31.6%) in AH system. The fruit yield partitioned 66.8% of the total monetary output in AH system. The

Table 56. Total labour input (hrs/ha/yr) for different crops grown at 2000 to 2500 m asl without integration of trees (control).

Season	Crop components	Human labour				Bullock labour
		Man	Woman	Child	Total	
Winter	Wheat	106.2	665.2	-	771.4	95.2
	Barley	114.3	576.3	95.2	785.8	102.4
Summer	Maize	197.2	602.1	397.2	1196.5	63.9
	Finger millet	232.9	478.7	85.3	796.9	112.0
	Amaranth	240.0	443.1	100.0	783.1	64.0
	Buck wheat	269.8	454.2	12.7	736.7	60.3
	Mustard	148.1	473.4	-	621.5	55.5
	Kidney bean	423.6	609.7	-	1033.3	95.5
	Potato (tuber)	218.7	680.6	291.7	1191.0	89.6

Bund area per ha of cultivated land was 0.032 ha; bullock= 1 Pair.

Crop rotation

Wheat---------------------- Maize---------------------------- 1 year (Rainfed)
Barley--------------------- Mustard------------------------- 1 year (Rainfed)
Finger millet--------------- Fallow---------------------------- 1 year (Rainfed)
Amaranth------------------ Fallow---------------------------- 1 year (Rainfed)
Buckwheat----------------- Fallow---------------------------- 1year (Rainfed)
Kidney bean--------------- Fallow---------------------------- 1 year (Rainfed)
Potato--------------------- Fallow---------------------------- 1 year (Rainfed)

Table 57. Seed rate input (kg/ha/yr ±SD) and fertilizer consumption (q/ha/yr ±SD) for different crops grown at 2000 to 2500 m asl without integration of trees.

Season	Crop components	Crops	Seed rate	FYM
Winter	Mono	Wheat	117.4±7.2	18.2±3.1
	Mono	Barley	85.7±5.8	17.9±3.0
Summer	Mono	Maize	50.0±4.5	17.5±2.5
	Mono	Finger millet	16.7±2.6	13.2±1.7
	Mono	Amaranth	4.5±1.1	16.7±2.6
	Mono	Buck wheat	66.7±5.0	14.5±1.8
	Mono	Mustard (var- Toria)	8.3±1.2	10.8±1.5
	Mono	Kidney bean	62.5±3.8	20.8±4.2
	Mono	Potato (tuber)	1450.0±68.9*	20.5±4.0

Crop rotations was same as mentioned in table 104, *Fresh wt. Basis.

Table 58. Crop productivity (q/ha/yr ±SD) at 2000 to 2500 m asl in control plots.

Season	Crop components	Crops	Productivity			
			Grain	Husk	Stem	Total crop byproduct
Winter	Mono	Wheat	16.5±3.6	5.4±1.7	18.2±4.0	23.6
	Mono	Barley	14.1±3.0	3.1±1.5	17.4±3.7	20.5
Summer	Mono	Maize	20.1±4.2	9.4±2.1**	28.8±3.5	38.2
	Mono	Finger millet	14.4±2.5	2.5±0.6	20.9±2.4	23.5
	Mono	Amaranth	4.7±1.1	13.2±3.5	41.1±5.7	54.3
	Mono	Buck wheat	8.2±2.0	-	16.7±2.0	16.7
	Mono	Mustard	4.5±1.5	4.8±1.5	8.8±1.5	13.6
	Mono	Kidney bean	15.5±3.0	6.3±2.0	6.1±1.1	12.4
	Mono	Potato (tuber)*	-	-	116.8±21.5	-

Crop rotations was same as mentioned in table 104, *Fresh weight basis** kernel weight.

Table 59. Comparative energy budget (Mj/ ha/yr) for the different crops grown without integration of trees at 2000 to 2500 m asl.

Season	Crop components	Inputs					Outputs				Net return	Output / Input ratio
		Human labour	Bullock power	FYM	Seed	Total inputs	Grain	Dry fodder	Bund grass	Total outputs		
Winter	Wheat	370.5	577.1	26550.1	1901.2	29398.9	26765.6	32791.5	202.8	59759.9	30361.1	2.0
	Barley	369.0	620.3	26068.3	1388.5	28446.1	22780.4	28524.2	234.0	51538.6	23092.5	1.8
Summer	Maize	546.1	387.1	25550.0	810.0	27293.2	32500.4	55320.4	245.7	88066.5	60773.3	3.2
	Finger millet	389.8	679.0	19345.0	269.9	20683.6	23344.2	34028.6	448.5	57821.3	37137.6	2.8
	Amaranth	386.7	387.8	24331.0	73.0	25178.5	7672.3	75513.1	471.9	83657.4	58478.8	3.3
	Buck-wheat	379.7	365.5	21199.2	1079.9	23024.2	13366.6	24657.2	425.1	38448.9	15424.7	1.7
	Mustard	302.6	336.6	15812.0	192.2	16643.4	10423.0	18901.2	214.5	29538.7	12895.3	1.8
	Kidney bean	512.6	578.6	30412.0	1062.5	32565.7	26438.4	17191.5	460.2	44090.1	11524.4	1.3
	Potato	524.5	542.8	30003.0	5655.0	36725.3	45552.0	-	436.8	45988.8	9263.5	1.2
Average*		**540.2**	**639.2**	**31324.4**	**1776.0**	**34279.9**	**29834.7**	**40989.7**	**448.5**	**71272.9**	**36993.0**	**2.1**

Crop rotations was same as mentioned in Table 104, *based on crop rotation.

Table 60. Monetary input and output (Rs/ha/yr) for different crops grown without integration of trees at 2000 to 2500 m asl.

Season	Crop compone-nts	Inputs					Outputs				Net return	Output/ Input ratio
		Human labour	Bullock power	FYM	Seed	Total inputs	Grain	Dry fodder	Bund grass	Total outputs		
Winter	Wheat	5086	1785	1819	939	9629	13,218	1179	52	14,449	4820	1.5
	Barley	4959	1919	1785	514	9177	8437	1026	60	9523	346	1.0
Summer	Maize	6977	1196	1750	400	10,323	16,050	1440	63	17,553	7230	1.7
	Finger millet	5349	2101	1325	83	8858	7205	1047	115	8867	9	1.0
	Amaranth	5244	1200	1666	135	8245	9472	-	121	9593	1348	1.2
	Buck-wheat	5248	1131	1452	1066	8897	11,551	833	109	12,493	3596	1.4
	Mustard	4255	1041	1083	117	6497	6325	239	55	6619	123	1.0
	Kidney bean	7517	1790	2083	1500	12,890	37,325	316	118	37,759	24,869	2.9
	Potato	7262	1679	2055	5800	16,796	58,400	-	112	58,512	41,716	3.5
Average*		**7414**	**1977**	**2145**	**1508**	**13,044**	**23,997**	**869**	**115**	**24,981**	**11,937**	**1.9**

Crop rotations was same as mentioned in Table 104, *based on crop rotation.

Table 61. Dominance and ecological success of tree species of agrihorticultural agroforestry system at 2000 to 2500 m asl (n =20 number of quadrats in the system).

Tree Species	Relative Frequency (%)	Relative Density (%)	Relative Dominance (%)	Importance Value Index (IVI)
Juglans regia	10.4	7.6	11.2	29.2
Prunus armeniaca	7.0	8.6	9.8	25.4
P. domestica	6.4	5.6	6.4	18.4
P. persica	7.7	9.6	5.9	23.2
Pyrus communis	22.6	20.2	20.9	63.7
P. malus	45.8	48.5	45.7	140.0

Table 62. Productivity of agrihorticultural agroforestry systems at 2000 to 2500 m asl.

Tree Species	Uses	Tree productivity (kg/tree/yr ±SD)	Control	Agrihorti AFS (kg/ha/yr ±SD)
Juglans regia	Fruit	33.0±6.5	-	291.7±57.9
Prunus armeniaca	Fruit	13.9±2.5	-	139.3±25.3
P. domestica	Fruit	17.6±6.0	-	114.9±39.2
P. persica	Fruit	6.9±2.1	-	77.5±23.6
Pyrus communis	Fruit	62.0±10.5	-	1464.1±248.5
P. malus	Fruit	66.2±12.5	-	3756.9±712.3
Total	Fruit (q/ha)	-	-	58.4±11.1
	Bund grass (q/ha)	-	1.1±0.3	1.2±0.3

Table 63. Total labour input (hrs/ha/yr) for different crops grown in agrihorticultural agroforestry system at 2000 to 2500 m asl.

Season	Crop components	Human labour				Bullock labour
		Man	Woman	Child	Total	
Winter	Wheat	99.1	862.4	-	961.4	88.8
	Barley	106.0	779.4	88.8	974.8	95.5
Summer	Maize	184.0	655.3	370.5	1209.9	59.6
	Finger millet	217.2	782.1	79.5	1078.8	104.5
	Buck wheat	251.7	759.2	11.8	1022.7	56.2
	Potato (tuber)	204.0	970.4	272.1	1446.6	83.6
	Mustard leaf	-	1079.2	-	1079.2	-
	Pumpkin	-	774.7	-	774.7	-
	Bottle gourd	-	785.7	-	785.7	-
	Cucumber	-	779.7	-	779.7	-

Bund area per ha of agrihorticultural agroforestry system was 0.032 ha;
Bullock= 1 Pair.

Crop rotation

Wheat-------------------------	Maize------------------------	1 year
Barley -----------------------	Mustard leaf---------------	1 year
Finger millet ----------------	Fallow-----------------------	1 year
Buck wheat-------------------	Fallow-----------------------	1 year
Potato-------------------------	Fallow-----------------------	1 year
Cucurbits---------------------	Fallow-----------------------	1 year

Table 64. Seed rate (kg/ha/yr ±SD) and fertilizer consumption (q/ha/yr) for different crops grown in agrihorticultural agroforestry system at 2000 to 2500 m asl.

Season	Crop components	Vegetables	Seed rate	FYM
Winter	Mono	Wheat	109.5±6.9	21.3±3.5
	Mono	Barley	80.0±4.6	21.0±3.7
Summer	Mono	Maize	46.6±4.2	17.1±1.6
	Mono	Finger millet	15.5±2.0	18.1±2.0
	Mono	Buck wheat	62.2±5.2	19.3±2.5
	Mono	Potato (tuber)	1352.8±45.7*	24.7±5.5
	Mono	Mustard leaf	14.0±2.3	21.4±4.1
	Mono	Pumpkin	6.4±1.0	18.9±3.5
	Mono	Bottle gourd	6.1±1.0	18.9±2.1
	Mono	Cucumber	2.8±0.4	18.6±3.4

Crop rotations was same as mentioned in Table 111, *Fresh weight basis.

Table 65. Crop productivity (q/ha/yr ±SD) in agrihorticultural agroforestry system at 2000 to 2500 m asl.

Season	Crop compon-ents	Crops	Productivity			
			Grain	Husk	Stem	Total crop byproduct
Winter	Mono	Wheat	14.9±3.7	4.8±1.1	16.4±2.5	21.2
	Mono	Barley	12.7±3.0	2.8±0.5	15.7±3.2	18.5
Summer	Mono	Maize	18.1±2.7	8.4±1.7**	25.9±3.7	34.3
	Mono	Finger millet	8.6±1.5	2.3±0.7	15.2±3.5	17.5
	Mono	Buck wheat	7.4±1.5	-	15.0±4.0	15.0
	Mono	Potato (tuber)*	-	-	105.1±21.5	-
	Mono	Mustard leaf*	82.1±10.1	-	-	-
	Mono	Pumpkin*	85.3±12.5	-	-	-
	Mono	Bottle gourd*	75.4±13.1	-	-	-
	Mono	Cucumber*	48.7±6.5	-	-	-

Crop rotations was same as mentioned in Table 111, *Fresh wt. basis, **Kernal wt.

Table 66. Comparative energy budget (Mj/ha/yr) for different crops grown in agrihorticultural agroforestry system at 2000 to 2500 m asl.

Season	Crop components	Inputs					Outputs					Net return	Output/ Input ratio
		Human labour	Bullock power	FYM	Seed	Total inputs	Grain/ vegetables	Dry fodder	Bund grass	Fruit	Total outputs		
Winter	Wheat	441.6	538.2	31088.4	1773.9	33842.2	24089.0	29512.3	245.7	77898.1	131745.1	97902.9	3.9
	Barley	440.2	578.7	30651.2	1295.3	32965.4	20502.4	25671.8	198.6	77898.1	124270.8	91305.4	3.8
Summer	Maize	544.7	361.0	24933.3	755.7	26594.8	29250.4	49788.4	226.2	9302.6	88567.6	61972.8	3.3
	Finger millet	496.8	633.3	26441.7	251.7	27823.6	13997.0	25405.7	499.2	87200.7	127102.6	99279.0	4.6
	Buck-wheat	487.4	340.9	28116.1	1007.5	29951.8	12030.0	20848.0	475.8	87200.7	120554.5	90602.7	4.0
	Potato	622.5	506.4	36065.8	5275.8	42470.5	40997.0	-	456.3	87200.7	128654.0	86183.5	3.0
	Mustard leaf	423.6	-	31266.0	323.0	32012.7	23002.0	-	276.9	9302.6	32581.5	568.8	1.0
	Pumpkin	305.9	-	27544.4	88.0	27938.2	20474.4	-	468.0	87200.7	108143.1	80204.9	3.9
	Bottle gourd	310.3	-	27661.2	83.9	28055.3	18100.8	-	491.4	87200.7	105792.9	77737.6	3.8
	Cucumber	308.0	-	27223.2	38.5	27569.7	11700.0	-	452.4	87200.7	99353.1	71783.4	3.6
Average*		**627.5**	**591.7**	**39339.8**	**1792.2**	**42351.2**	**31915.5**	**37806.5**	**474.9**	**87200.7**	**157397.6**	**115046.4**	**3.7**

Crop rotations was same as mentioned in Table 111, *based on crop rotation.

Table 67. Monetary input and output (Rs/ha/yr) for different crops grown in agrihorticultural agroforestry system at 2000 to 2500 m asl.

Season	Crop compon-ents	Inputs					Outputs					Net return	Output/ Input ratio
		Human labour	Bullock power	FYM	Seed	Total inputs	Grain/ vegetables	Dry fodder	Bund grass	Fruit	Total outputs		
Winter	Wheat	6257	1665	2130	876	10,928	11,896	1061	63	32,154	45,174	34,246	4.1
	Barley	6136	1790	2100	480	10,506	7593	923	51	32,154	40,721	30,215	3.9
Summer	Maize	7095	1117	1708	373	10,293	14,445	1296	58	5959	21,758	11,465	2.1
	Finger millet	7087	1959	1811	78	10,935	4320	762	128	38,113	43,323	32,388	4.0
	Buck-wheat	6991	1055	1926	871	10,843	10,396	798	122	38,113	49,399	38,556	4.5
	Potato	8870	1567	2470	5411	18,318	52,560	-	117	38,113	90,790	72,472	5.0
	Mustard leaf	6745	-	2141	252	9138	24,645	-	71	38,113	30,675	21,537	3.4
	Pumpkin	4842	-	1887	512	7241	34,124	-	120	38,113	72,357	65,116	9.9
	Bottle gourd	4911	-	1895	488	7294	30,168	-	126	38,113	68,407	61,113	9.4
	Cucumber	4873	-	1865	336	7074	24,375	-	116	38,113	62,604	55,530	8.8
Average*		**9009**	**1831**	**2695**	**1464**	**14,999**	**18,018**	**807**	**122**	**38,113**	**57,060**	**42,061**	**3.8**

Crop rotations was same as mentioned in Table 111, *based on crop rotation.

Table 68. Comparative energy input and output (Mj/ha/yr) patterns for different crops grown in control and agrihorticultural agroforestry system at 2000 to 2500 m asl.

Parameters	Control	Agrihorti (AFS)
Inputs		
Human labour	540.2 (1.6%)	627.5 (1.5%)
Bullock labour	639.2 (1.9%)	591.7 (1.4%)
FYM & fertilizers	31324.4 (91.4%)	39339.8 (92.9%)
Seed	1776.0 (5.2%)	1792.2 (4.2%)
Total inputs	**37265.2**	**42351.2**
Outputs		
Grain/vegetables yield	29834.7 (41.9%)	31915.5 (20.3%)
Crop residue	40989.7 (57.5%)	37806.5 (24.0%)
Fodder from weed & grasses of the bunds	448.5 (0.6%)	474.9 (0.3%)
Fruit from agroforestry trees	-	87200.7 (55.4%)
Total outputs	**71272.9**	**157397.6**
Output/ Input ratio		
Grain/vegetables	0.9	0.7
Grain + Crop residue	2.1	1.6
Grain + Crop residue + Bund grass	2.1	1.7
Grain + Crop residue + Bund grass + Fruit	-	3.7

Values in parenthesis represent per cent contribution to total energy input and output of the respective parameters.

Table 69. Comparative average annual monetary (Rs/ha/yr) input and output patterns for different crops grown in control and agrihorticultural agroforestry system at 2000 to 2500 m asl.

Parameters	Control	Agrihorti (AFS)
Inputs		
Human labour	7414.0 (56.8%)	9009.0 (60.0%)
Bullock labour	1977.0 (15.2%)	1831.0 (12.2%)
FYM & fertilizers	2145.0 (16.4%)	2695.0 (18.0%)
Seed	1508.0 (11.6%)	1464.0 (9.8%)
Total inputs	**13,044.0**	**14,999.0**
Outputs		
Grain/vegetables yield	23,997.0 (96.1%)	18,018.0 (31.6%)
Crop residue	869.0 (3.5%)	807.0 (1.4%)
Fodder from weed & grasses of the bunds	115.0 (0.5%)	122.0 (0.2%)
Fruit from agroforestry trees	-	38,113.0 (66.8%)
Total outputs	**24,981.0**	**57,060.0**
Output/ Input ratio		
Grain/vegetables	1.8	1.2
Grain + Crop residue	1.9	1.2
Grain + Crop residue + Bund grass	1.9	1.3
Grain + Crop residue + Bund grass + Fruit	-	3.8

Values in parenthesis represent per cent contribution to total monetary input and output of the respective parameters.

output: input ratio has also been worked out keeping in view the different crops and crop byproducts. Taking into consideration the range of grain/vegetables productivity, output: input ratio was 1.8 in control and 1.2 in AH system, respectively. Calculating the total biological yield, the range of output: input ratio was observed to be 1.9 and 3.8, respectively, in control and AH system.

Biomass Consumption

Firewood consumption along an altitudinal gradient in Kumaun Himalaya has been estimated. On average, the firewood consumption was recorded to be 1.07, 1.42, and 2.80 kg/capita/day, respectively, at 380-500, 1000-1500, and 2000-2500 m altitude, which indicated that firewood consumption increased with increase in altitude. Firewood consumption was 2.61- fold higher at high altitude (2000-2500 m asl) compared to fuelwood use at low (380-500 m) altitude. On an average, firewood consumption was maximum during winters at all the altitudes, followed by spring and rainy season. The annual firewood consumption was 392.4, 517.4 and 1019.3 kg/capita, respectively, at 380-500, 1000-1500 and 2000-2500 m altitude (**Table 70**).

Labour energy expenditure for firewood consumption has also been recorded. At each altitude, female members contributed maximum energy for firewood collection compared to male counter part of the family. Labour energy expenditure was directly related to availability of the biomass for firewood, distance travelled to collect the firewood and firewood consumption pattern etc. Therefore the total energy expenditure (Mj/capita/yr) was lowest (60.8) at high altitude (2000-2500 m) and highest (87.2 Mj/capita/yr) at low (500-1000 m) altitude, followed by 380-500 m altitude (85.1 Mj/capita/yr). On average, male counter part of the family contributed 36.0-48.0% labour energy for firewood collection, irrespective of altitude. Villagers walked on an average, 1.3-3.0 km in search of firewood collection (**Table 71**).

Besides, firewood, kerosene, LPG and cowdung were also used as a source of energy. Particularly at 380-500 and 1000-1500 m altitude Kerosene, LPG and cowdung met out > 20% energy requirement at 380-500 m altitude, whereas, use of these sources of energy was restricted to < 3.0% at 1000-1500 m altitude, and beyond 1500 m altitude, firewood was the only source of energy.

On average, total energy consumption was estimated to be 27.5, 28.7 and 55.5 Mj/capita/yr, respectively, at 380-500, 1000-1500 and 2000-2500 m altitude, and there was 2.0- fold higher energy consumption at high altitude (2000-2500 m) compared to low altitude, *i.e.*, 380-500 m elevation (**Table 72**).

Fodder consumption for category of livestock along an elevational transect has also been recorded. Among various category of animals, green as well as dry fodder consumption was highest for buffalo, followed by ox and cow, respectively. The range of green fodder consumption was 12.67-19.00, 10.33-13.25 and 2.38-4.25 kg/cattle/day, respectively, to buffalo, cow, ox, calf and sheep/ goat, being average value of 16.4, 11.8 and 3.3 kg/cattle/day, accordingly, to the same category of animals, irrespective of altitude. Dry fodder consumption was, respectively, 2.7, 2.1 and 1.3 kg/cattle/day to buffalo, cow, ox and calf. Inter-comparing the fodder consumption at different altitudes, it has been observed that the green fodder consumption was highest (10.2 kg/cattle/day) at 2000-2500 m altitude and lowest (7.9 kg/cattle/day) at 380-500 m altitude, irrespective of the livestock component. Similarly, the dry fodder consumption was 2.5 and 1.5 kg/cattle/day, respectively, at 2000-2500 and 380-500 m altitude (**Table 73**).

Female member of the family consumed maximum energy for fodder collection at each elevational gradient except that of 380-500 m altitude. The total labour energy expenditure was recorded to be 157.7, 124.1 and 107.8 Mj/capita/yr, respectively, at 380-500, 1000-1500 and 2000-2500 m altitude. Similar to labour energy expenditure to firewood collection, the energy expenditure for fodder collection also depends on availability of the biomass, number of livestock reared and distance travelled for collection of fodder. Due to lesser number of cattle populations at higher altitude and availability of the biomass in plenty, less energy was required for fodder collection compared to low altitude (**Table 74**).

Table 70. Firewood consumption pattern (kg/capita/yr±SD) along an altitudinal gradient.

Season	Altitudinal range (m asl)		
	380 to 500	1000 to 1500	2000 to 2500
Rainy	313.9±51.1	427.0±43.8	934.4±61.5
Winter	605.9±92.0	733.7±78.6	1376.1±88.2
Spring	430.7±84.7	558.5±84.6	1065.8±69.5
Summer	219.0±31.1	350.4±58.4	700.8±32.9
Average/ yr	392.4	517.4	1019.3
Average/ day	**1.1**	**1.4**	**2.8**

Table 71. Labour energy expenditure (Mj/capita/yr ±SD) for collection of firewood at different altitudes by the household.

Family member	Altitudinal range (m asl)		
	380 to 500	1000 to 1500	2000 to 2500
Male	40.7±2.1	30.2±1.5	21.8±1.0
Female	32.9±1.7	35.2±2.4	33.7±2.1
Child	11.5±0.9	11.3±0.9	5.1±3.0
Total energy	85.1	76.7	60.8
d⁻ (km)	2.5	2.0	1.3

d⁻ average distance of forest from village.

Table 72. Total energy consumption (Mj/capita/yr ±SD) at different altitudes.

Application	Altitudinal range (m asl)		
	380 to 500	1000 to 1500	2000 to 2500
Fuelwood	21.1±1.5	27.9±2.7	55.1±3.9
Kerosene	0.1±0.0	0.3±0.2	0.4±0.0
LPG	0.6±0.1	0.4±0.3	-
Cow dung	5.8±0.6	-	-
Total energy	27.5	28.7	55.5

Table 73. Fodder consumption (Kg/cattle/day ±S.D.) along an altitudinal gradient by different category of livestock.

Type of animals	Altitudinal range (m asl)					
	380 to 500		1000 to 1500		2000 to 2500	
	Green fodder	Dry fodder	Green fodder	Dry fodder	Green fodder	Dry fodder
Buffalo	12.7±1.4	3.0±0.1	17.5±1.1	4.0±0.4	19.0±2.5	4.0±0.4
Cow	9.7±1.7	1.5±0.3	12.0±0.7	2.0±0.4	11.8±0.0	2.0±0.4
Ox	10.3±1.5	1.7±0.1	12.3±1.9	2.9±0.5	13.3±1.9	2.9±0.5
Calf	4.3±0.3	0.7±0.1	3.2±0.1	0.9±0.2	4.3±0.4	0.9±0.2
Sheep/ Goat	2.4±0.3	-	4.1±0.9	-	2.5±1.6	-
Total	39.3	6.0	49.1	8.9	50.9	9.8
Average/ cattle/ day	7.9	1.5	9.8	2.2	10.1	2.3
Average/ cattle/ yr	2868.9	547.5	3587.95	806.7	3715.7	894.3
Grazing time (hrs)	5 – 6		3 – 4		2 - 3	

Table 74. Labour energy expenditure (Mj/capita/yr ±SD) for collection of fodder at different altitudes by the household.

Family member	Altitudinal range (m asl)		
	380 to 500	1000 to 1500	2000 to 2500
Male	80.9±6.2	49..3±2.0	46.3±2.1
Female	65.4±3.3	57.4±2.0	56.0±3.5
Child	11.4±1.2	17.4±1.5	5.5±1.0
Total energy	157.7	124.0	107.8
d¯ (km)	2.5	2.0	1.3

d¯ average distance of forest/ surrounding area from village.

GENERAL DISCUSSION

The world population is growing very fast. In 1950 it was 2.5 billion and increased to 5.3 billion by 1990. The projection for 2030 shows the world population rising to 8.9 billion. There is a growing disparity between the expanding world population and the earth's food producing capacity, as a result, food supplies per capita are decreasing. The world food summit convened by FAO in 1997 predicted that food and feed production in developing countries must be tripled by the year 2050 to cater for the demand created by the doubling of the human population and their increasing aspiration for a higher standard of living. The data on food production indicates that during 50s to the 70s, there was high production, mainly due to Green Revolution. But during the post Green Revolution era, increase in major food commodities declined markedly to level which will not sustain the proposed requirements by 2050 (Brown and Kane, 1994).

In the third world countries, some 2.3-2.6 billion people are supported by agricultural systems characterized by modern technologies brought about by the Green Revolution. These systems utilize good soils and usually have reliable access to water. However, these systems are not applicable to the 1.9-2.2 billion (82.6-84.6%) people living in rainfed, undulating and mountainous areas, which are largely untouched by modern technologies. Their agricultural systems are complex and diverse, and are located in the humid and sub humid areas, the hills and mountains and the dry lands of uncertain rainfall. They commonly produce only one-fifth to one-tenth per unit area of food compared to farms in the industrialized and Green Revolution lands (Pretty, 1995).

The green revolution belt of the country has already reached production plateau besides leading to environmental hazards and resultant impact on human health thereby bringing in increased concern for sustainability. Such concerns have given rise to the concept of evergreen revolution through alternative farming system methods like agroforestry, integrated farming systems, organic farming and/or biodynamic farming etc. Such farming practices are largely dependent on organic sources of fertilizers, recycling of within-farm renewable resources and off farm wastes.

India occupies 2% of the world's geographical area, 16% of its population and 12% livestock. At the time of independence, the country had a total population of 350 million and produced only 51 million tonnes of food grain. Today the population has crossed 1 billion marks and food grain production has also increased to 200 million tonnes. However, the major share of food grain production (55%) has been achieved from 37% of the cultivated areas, which have good soils and have access to water, whereas only 45% of the food grain is produced in the remaining 63% rainfed areas. An analysis of the food production indicates that production from the high input belts, *i.e.*, from the 37% areas have almost reached a plateau. The emphasis, therefore, should be given to increase the production from 63% rainfed agriculture where agricultural systems are complex, diverse and risk prone (CDR). It depends on the recycling of within farm resources and off farm waste (Bujarbaruah, 2004). Crop rotation, mixed farming and intercropping etc are some of the characteristics of CDR agriculture. However, the sustainable use of natural renewable resources will be facilitated when the feed is grown, the animals are fed and the excreta is recycled on the farm in ways that minimize the use of imported inputs including energy (Preston and Murgueitio, 1994).

Talking historically, Kumoun Himalaya had a healthy tradition of harmonious relationship between people and their rich forest heritage. To quote Walton (1911a), '*the most productive cultivation in the mountains was found in villages between 1,000 and 1,500m that had access, on the one hand, to good forest and grazing ground and, on the other, to riparian valley fields. Villages were usually situated halfway up a spur, below oak forests and perennial springs, and below and above cultivated fields along a river course*'. Animal husbandry, in addition to grain cultivation, was important feature of the hill economy. The people and their cattle migrated annually to the rich grasslands within the forests, from tropical to temperate and alpine regions. Temporary cattle shed were constructed there and the potato (introduced in the post-British era) and buckwheat were cultivated. Sheep and goats were reared above tree line until the first snowfall. In permanent hamlets, oak forests provided both fodder and fertilizer. Green and dry leaves were molded for manure and, thus, the forest enhanced the fertility of the agriculture fields, directly through its foliage and indirectly through the dung of cattle fed with fodder leaves and forest

grass. Broad-leaved trees also provided the villagers with fuel and small timbers for house construction and agricultural implements (Heske, 1931).

In the lower hills, extensive chir (*Pinus roxburghii*) forest served for pasture. Every year, dry grass and pine-needle litter in the chir forest were burnt to make room for a fresh crop of luxuriant grass. In certain areas where pasture was scare, trees were preserved for fodder (Pauw, 1896). In such multifarious ways the extensive forests were central to the successful practice of agriculture and animal husbandry. In addition, they were the prime source of medicinal herbs. Forests also helped hill people to overcome moderate food scarcity as they were rich in fruits, edible vegetables and roots (Walton, 1911b).

This dependence of the hill peasant on forest resources was the basis for various social and cultural institutions. Communal activities were organized and included management of village grazing grounds and fuel and fodder reserves, despite official apathy. The old traditional restrictions on the use of the forests applied over large areas. While neither there was nor was formal management, practical protection secured by customary limitations on use. For oak forest, there was an unwritten rule, which prohibited the lopping of leaves in hot weather, while grass cutting by each family was strictly regulated (Pearson, 1969). Traditionally, many villages had some forest reserved for fuel even on *gaonsanjait* (common village land measured by government), where villagers would cut in regular rotation by common consent. The planting of timber trees was a fairly common phenomenon. The forest boundaries were zealously guarded by nearby villages. In Tehri State, peasants strongly asserted their claim to species such as Bhimal (*Grewia oppositifolia*), a valuable fodder tree usually found near habitations (Raturi, 1910). In British Kumoun, Chaundkot pargana was singled out for its oak forest within the village boundaries, known as *bani* or *banhanis*, where branches of trees were cut only at specified times and with the permission of the entire village community (Stowell, 1907). Today in remote areas, untouched by commercial exploitation of forests, one can still come across well-maintained *banjanis* containing oak trees of a quality rarely observed elsewhere (Guha, 1989).

Hill villages are generally much smaller and far less economically stratified than villages in the plains. Holdings are small and relatively equal. Land ownership of more than two hectares seems uncommon and of more than four hectares seems uncommon and of more than four hectares almost unheard of. There are rare landless agricultural labourers. Here Schedule Caste and Schedule Tribes all have their own houses and small land holdings. In each of the districts, less than 2% of the work force is agricultural labourers while over 70% are cultivators (Government of India, 1981).

The agriculture system of the region is closely linked with forestry and livestock. Almost all the farming families rear cattle for milk in general and farmyard manure in particular. According to an estimate, 1 unit energy from agriculture requires 12 energy units from firest biomass energy. Further, it has also been estimated that annually a hectare of cultivated land requires 11.5 tonnes of fodder, 7.4 tonnes fuelwood and 3.4 tonnes of bedding leaves in the Central Himalaya (Singh *et al.*, 1984). Cattle (cow and bullock), buffalo, sheep and goat are important livestock of the region. The region has 6.08 million livestock population. Cattle, buffalo, sheep and goat, respectively, represent 44.0, 24.2, 6.9 and 24.0% population. In all the districts of the region, cattle population, by and large, remained highest followed by goat. The total livestock population, however, was found highest (1.78 million) in Pauri and lowest in Rudraprayag district (0.256 million). On an average, the region has only 0.463 million ha (15.4%) of gross cropped area as against the total geographical area of 3.009 million ha. The area under non-agricultural uses accounted for 0.071 million ha.

Phytosociology of Agoforestry Trees

In rainfed agriculture, various multipurpose tree species are cultivated or allowed to grow in or around agricultural fields across an altitudinal gradient. *Albizia lebbek, Boehmeria rugulosa, Celtis australis, Ficus* spp., *Grewia optiva, Morus* spp., *Ougeinia oojeinensis, Toona ciliata* and *Quercus leucotrichophora* etc has been found major multipurpose tree species in Kumaun Himalaya. The important fruit trees of the region include *Artocarpus heterophyllus, Carica papaya, Citrus* spp., *Juglans regia, Mangifera indica, Prunus* spp., *Pyrus* spp. and *Psidium*

guajava. The tree density/ha of various multipurpose tree species in AS system was recorded as 150, and 136, respectively, at 380-500 and 1000-1500 m asl, irrespective of species. Above 2000 m altitude, multipurpose tree species are not grown in agricultural fields. So far tree density of individual species in AS system was concerned; it was found highest (27.24) to *Q. leucotrichophora*, followed by *G. optiva* (26.0) and *Mallotus philippenensis* (22.6), irrespective of altitude. In AH system, the tree density was 114.3, 124.9, and 117.0, respectively at 380-500, 1000-1500, and 2000-2500 m altitude, irrespective of species. Among various species, the tree density/ha was highest (42.6) to *Pyrus malus*, followed by *Citrus aurantifolia* (32.2), *C. sinensis* (31.3), *C. limonia* (25.3), *Musa paradisica* (21.8) and *P. communis* (21.7). In AHS system, the tree density per ha was 241.4, and 170.9, respectively, 380-500 and 1000-1500 m altitude. Among various species, tree density per ha was highest to *C. aurantifolia* (33.7), followed by *M. paradisica* (28.6) and *G. optiva* (20.8). Tree density/ha in SP system was 280.6, at 380-500 altitude, and among various species, tree density was highest to *G. optiva* (47.0), followed by *Melia azedarach* (34.9) and *Bauhinia variegata* (24.4). Thus the tree density/ha was 132.3, 124.4, 208.2 and 249.4, respectively, in AS, AH, AHS and SP agroforestry systems, irrespective of altitude and species.

In an earlier study, Nautiyal *et al.* (1998) recorded tree density of 390 per ha in Pali village of Garhwal Himalaya, which seems significantly high probably due to location specific agroforestry practice. However, other findings have shown the tree density in simultaneous agroforestry system of Garhwal Himalaya in the range of 182 to 419 trees/ha and species richness from 8-90 species (Toky *et al.*, 1989a; Sundriyal *et al.*, 1994; Thapa *et al.*, 1995; Semwal and Maikhuri, 1996) compared to 36 tree-crops observed in the present study. A wide variation in data could be accounted for as due to variation in spatial scale of observation (plot level to a cluster of villages/ watershed which means variation in environmental heterogeneity and gradient sampled e.g. elevation covered in the present study varied from 380 to 2500m asl), variation in methodology (quadrat sampling by some and questionnaire/ participatory survey by others) together with huge variation in ecological and socio economic factor (Nautiyal *et al.*, 1998).

In the central Himalayan village ecosystems, three traditionally predominant agroforestry systems were the agricultural, silvicultural and horticultural entities. Following the Nair (1985c) classification, they should have been termed as agrisilviculture systems, as he grouped different silvicultural and horticultural trees under silviculture entity only. Thus, the sequential position of agriculture or silviculture or pastoral entity is fixed, whereas in nature, it is not necessary that these components are always superior. Above all, these systems are classified on need base, which is only applicable in specific situations. However, through this study of sequential classification, they emerged out to be agrisilviculture (AS), agrihorticulture (AH), agrihortisilviculture (AHS) and silvipastoral (SP) systems. As this classification is based on structural and functional aspects of each species, the IVI values identified the sequential order of ecologically most successful/important species in the system. The predominance of the entity was clearly spelled out, irrespective of its being a tree or an agricultural crop e.g. AHS system.

Importance Value Index (IVI) exercise not only emphasizes the species density, frequency and abundance but also takes into consideration species relative status in each system. This classification encompasses the economical (need) as well as ecological (species adoptation potential) aspects of the system and one is not baised about any particular species. Above all, it is based on primary data and not on secondary data which reduces the variability of classification and also has replicability (Atul *et al.*, 1990). Important Value Index (IVI) which observed that *G. optiva* was the dominant species up to 1000 m altitude being the IVI values 63.9 at 380-500 m altitude in AS system. At 1000-1500 m altitude, however, *C. australis* was the most dominating species being IVI values of 66.21 and 44.2, respectively, in AS and AHS system. *O. oojeinensis* and *G. optiva*, respectively, ranked second and third at this altitude in dominance. Beyond 1500 m altitude, *Q. leucotrichophora* followed by *C. australis* and *G. optiva* were the most dominating species being IVI values of 103.5, 54.01 and 44.31, accordingly. In silvipastoral system, 15 tree species were found up to 1000m altitude. Among various species, *Dalbergia sissoo* and *Grewia optiva* were the most dominating, respectively, at 380-500 m altitude being the IVI values 57.14 accordingly to the same species.

systems along an elevational gradient, *G. optiva, C. australis, Q. leucotrichophora, O. oojeinensis, Toona ciliata, B. rugulosa, Dalbergia sissoo* followed by *Ficus* spp. have been found most dominating compared to others. So far IVI of important horticultural species was concerned, *Citrus aurantifolia*, was the most dominating species in AH system at 380-500 m altitude being the IVI value of 83.7, whereas it was the *C. sinensis* which showed highest IVI value at 1000-1500 m altitude having the IVI values of 60.63. On the other hand, beyond 2000 m altitude, *Pyrus malus*, followed by *P. communis* and *Juglans regia* were the most dominating species having IVI values of 140.01, 63.71 and 29.2, respectively. Interestingly in AHS system, multipurpose tree species were most dominated compared to fruit trees at each altitude. The present findings seems well within the range as reported by earlier workers for Western and Central Himalayan agroforestry systems (Toky *et al.*, 1989a; Atul *et al.*, 1990; Punam, 1989; Bhatt, 1991; Uniyal, 1998; Saklani, 1999, Bhatt and Todaria, 1990 a,b; Chauhan *et al.*, 1993; Bhatt *et al.*, 1995; Uniyal *et al.*, 1999; Dadhwal *et al.*, 1989; Todaria and Bhatt, 1992; Bhatt and Badoni, 1995; Maikhuri *et al.*, 1997b and 1997C).

Out of 0.46 million ha of gross cropped area, agrisilvi (AS), agrihorti (AH) and agrihortisilvi (AHS) systems occupy, respectively, 0.102, 0.03 and 0.026 million ha. It indicates that AS, AH and AHS system represents, respectively, 22.2, 6.5 and 5.7% area of the total cultivated land. Similarly, out of 0.071 million ha of non-agricultural land, silvipastoral (SP) system was practiced over 14.1% of the area. Thus agroforestry was practiced over 0.159 million ha area, representing 29.8% area under tree based farming, irrespective of agroforestry systems.

Fuel, Fodder, Fibre and Fruit Productivity in Agroforestry Systems

The total average tree fodder yield was recorded to be 19.04 and 26.1 q/ha/yr, respectively, in AS, AHS and SP systems. Similarly, the firewood yield was recorded to be 9.60 and 12.1 q/ha/yr, respectively, from the same systems. The fibre yield was 0.10 and 0.19 q/ha/yr from AS, AHS and SP systems, irrespective of altitude, and the average fruit yield was 36.17 and 27.41 q/ha/yr, respectively,

fodder, fuelwood, fibre and fruit was recorded to be 14.90 and 31.80 q/ha/yr, irrespective of altitude and land use systems, indicating significant (P = 0.01) inverse correlation between altitude and fruit yield. Among various altitudes, fodder and fuelwood yield was highest at 1000 to 1500 m altitude being the average value of 21.70 and 11.81 q/ha/yr, respectively. Fruit yield was maximum (58.45 q/ha/yr) at 2000 to 2500 m altitude in AH system.

At species level, *Boehmeria rugulosa, Celtis australis, Grewia optiva, Ficus auriculata, Melia azedarach, Ougeinia oojeinensis* and *Morus alba* exhibited the highest fodder yield being the average values of 2.66, 2.89, 3.21, 0.90, 2.27 2.41 and 1.77 q/ha/yr, irrespective of altitude. The fuelwood yield was 1.17, 1.62, 1.50, 0.35, 1.17, 1.26 and 1.08 q/ha/yr, accordingly to the same species. Among fruit trees, maximum fruit yield was recorded for *Citrus sinensis, Pyrus communis* and *Pyrus malus* being the yield values of 8.97, 8.55 and 16.56 q/ha/yr, respectively, irrespective of altitude and land use systems. In an earlier study, Punam (1989) also recorded the fodder, fuelwood and fruit yield of three types of traditional agroforestry systems of Himachal Himalaya. Tree fodder yield was reported to be 10.10 and 21.5 q/ha/yr, respectively, in AS and AHS systems. Similarly, fuelwood yield was 37.0 and 78.0 q/ha/yr (fresh weight basis) for the same systems. Annual fruit productivity was recorded to be 87.55 and 78.03 q/ha/yr, respectively, in AH and AHS systems. In another study, Toky *et al.* (1989a) recorded the fodder productivity of 25.85 and 55.97 q/ha/yr and fuelwood yield of 19.45 and 25.93 q/ha/yr (fresh weight basis), respectively, in AS and AHS systems of Himachal Pradesh. Fruit yield was recorded to be 87.55 and 78.02 q/ha/yr, respectively, in AH and AHS systems. These findings also supports to our results. Further, the present findings are in confirmity with the earlier observations of Carlowitz (1986), Roy (1992), Negi *et al.* (1979), Vishwantham *et al* (1999) and Gairola *et al.* (1990).

It has also been recorded that out of the total green fodder of 0.29 million tonne from agricultural land, different agroforestry systems contributed 0.22 million tonne of fodder, irrespective of tree species. AS, AHS and SP system, respectively, contributed 86.5, 12.5 and 1.07% green fodder. Rest of the green fodder, *i.e.*, 0.07 million tonnes was produced from the perennial grasses raised

on terrace risers and the weeds associated with cultivation of different crops. Similarly, out of the total dry fodder production of 1.80 million tonnes, different agroforestry systems showed the dry fodder production of 0.505 million tonne. Thus 28% of the total dry fodder production was shared by the agroforestry alone. AS, AHS, SP and AH agroforestry systems, respectively, contributed 73.0, 11.9, 0.24 and 14.65% to total dry fodder yield.

Fodder and Fuelwood Consumption Pattern

The fodder (green and dry) demand of the livestock is met from different sources like tree leaves, weeds and grasses, dry grasses, and crop byproduct. The average green and dry fodder consumption was estimated as 9.4 and 2.1 kg/cattle/day, irrespective of altitude and the category of livestock. The average green fodder consumption was 7.86, 9.83 and 10.18 kg/cattle/day, respectively, at 380-500, 1000-1500 and 2000-2500m altitude, irrespective of livestock category. However, among various category of livestock, fodder consumption was highest to buffalo, irrespective of altitude and lowest to goat/sheep. The dry fodder consumption varied from 1.50 to 2.45 kg/cattle/day with average value of 2.08 kg/cattle/day, irrespective of altitudinal variations. In an earlier study, Punam (1989) recorded the fodder consumption of 8.7 kg/cattle/day for different livestock in Himachal Himalaya. Arora and Porwal (2002) reported green and dry fodder requirement of 5.2 and 6.4 kg/cattle/day in Central Himalaya whereas, Agrawal and Joshi (1993) has reported that 14.0 kg of green and 2.95 kg of dry fodder is required to rear one cattle in the outer range of Kumoun Himalaya. In another study, Nautiyal and Nautiyal (1988) reported that 8.6 kg of green and 0.4 kg of dry fodder is consumed by different livestock in Garhwal Himalaya. Compared to Central Himalaya, the fodder consumption was very high in Eastern Himalaya. Sundriyal *et al.* (1994) reported fodder consumption in Sikkim Himalaya as 25.0 – 30.0 kg/cattle/day on fresh weight basis. It might be due to the fact that fodder consumption by different livestock increses or decreses according to altitudinal variation, geographical conditions, availability of grazing land, grazing time and type of livestock reared, *i.e.*, local/ crossbred.

Per hectare production of green as well as dry fodder has already been mentioned in result section. Based on fodder consumption by each category of livestock, it has been estimated that 17.87 million tonnes of green fodder and

3.37 million tonnes of dry fodder would be required to support 6.08 million population of livestock. So far fodder production was concerned, it has been recorded that the gross cropped area (*i.e.*, 0.46 million ha) and non-agricultural land (0.071 million ha) could produce 0.29 million tonnes of green fodder and 1.80 million tonnes dry fodder. Thus, agriculture of the region fulfills, respectively, 2.0 and 53% requirement of green and dry fodder including the fodder production from different agroforestry systems. Rest of the green and dry fodder is collected from the forests.

Firewood was one of the main sources of energy in Garhwal Himalaya. Approximately 80% rural population of the region use firewood to meet out their energy requirements. The average firewood consumption was 1.07, 1.42 and 2.80 kg/capita/day, respectively, at 380-500, 1000-1500 and 2000-2500m altitude. On an average, 1.7 million tonnes of firewood was required per annum to meet out the energy requirements of rural folk of Kumoun Himalaya. The firewood production from different agroforestry systems has been recorded as 0.22 million tonne/yr and its 70% was contributed by AS system. It indicated that agroforestry helped to supplement 13% of the total firewood requirement of rural populace. Rest of the firewood is collected from community forest/ private forest and/or reserve forests.

A large part of third world depends primarily on biomass fuel (low-energy sources), as opposed to fossil fuels (high-energy sources), relied upon in the developed world. The entire Himalayas primarily use biofuels and where the people are still at the subsistence economy level and faced with the problem of dwindling availability of biomass energy sources. The continuos heavy consumption of fuelwood has contributed to deforestation of these hills (Bhatt *et al.*, 1994).

Past studies have witnessed that up to the beginning of 20th century, there was commercial exploitation of forests, which contributed significantly in the destruction of forest resource in the region (Negi *et al.*, 1997). With the substantial increase in human and farm animal populations coupled with decreasing forests, the people of the region are facing acute scarcity of fuel

(Negi *et al.,* 1999). The demand for firewood is calculated as 1.7 million tonnes as against of 30-40 Mt production of firewood production (Anonymous, 1985).

In central Himalaya, the only cost of fuelwood collection is physical effort and time taken. The present study showed that fuelwood consumption at five altitudes ranged from 1.1 to 2.8 kg/capita/day. The value recorded are in the range of those reported for the rural and tribal communities of the Western Himalayas (1.49 kg/capita/day) by Bhatt *et al.* (1994), for Southern India (1.9-2.2 kg/capita/day) by Reddy (1981) and Hedge (1984), for South and South-East Asian countries (1.75-2.5 kg/day) by Donovan (1981) and Wijesinghe (1984), and Himalayan range of Nepal (1.23 kg/capita/day) by Mahat *et al.* (1987). The firewood consumption was also influenced by climate and the seasonal consumption per capita increased about 2-fold during winter.

On the basis of the fuelwood consumption pattern at different altitudes, it is important to seriously consider the problem of deforestation. It is important to note that if the current trends of fuelwood consumption continue in the region, there will be a scarcity of fuelwood supply in the near future. Most of the poor families use fuelwood also for lighting because of the paucity of kerosene and electricity. Low altitude populations expend more energy for collecting firewood because of the shortage of fuelwood in lower Himalayan region.

In addition to low percentage of forests (39.7% vs. the prescribed 66% for the hills), the forest density is also low in the study area. Of the 39.7% forested areas 40-50% of forests are of poor density. Moreover, nearly 8% of the total geographical area has serve soil erosion problems. About 80% of the non-forested area has slopes greater than 50%. A further factor is the higher concentration of grazing animals in the region (Anonymous, 1981; Negi, 1992; Negi and Todaria, 1993). In the Nainital districts of Kumoun Himalaya, there are cattle, buffaloes, sheep and goat, which range free and on the pasture in the forest. Lopping of broad-leaved trees in the forest for fodder complicates the situation. Under the present circumstances there is no viable alternative to firewood as a source of basic energy for people living at the subsistence level. Although mini/micro hydroelectric schemes are said to be particularly suitable for these areas due to suitable terrain and water resources (Shah and Pant, 1987),

it is a high – cost technology and is unlikely to be economically viable. Thus firewood remains the main source of energy in the region.

Although firewood consumption of northwestern Himalayan region is significantly lower (Bhatt *et al.*, 1994) than that of tribal communities in northeastern Himalayan region (Bhatt and Sachan, 2004), extensive fuelwood farming is needed coupled with mass popularization of improved chullahs. Species with high calorific value high-density wood, low ash and moisture content should be encouraged to be grown on abandoned or degraded lands, community lands or private land. It will be serve the twin purposes of forest conservation and fuelwood supply. The promising firewood species have already been the documented for different altitudes (Bhatt and Badoni, 1990; Bhatt and Todaria, 1990a; 1992; Negi and Todaria, 1993; Purohit and Nautiyal, 1987).

Crop Diversity

There exists large crop diversity in hill agro-ecosystem of Garhwal hills. The crop diversity was found highest (30 crops) up to 1000 m altitude. Beyond 1000m altitude, the diversity ranged from 9-11. On average the crop diversity in rainfed agriculture was found to be 14.2 as against of 4.4 in irrigated land, irrespective of altitude, cropping season and different land use systems. Across an altitudinal gradient, the crop diversity was 17.75, 12.25 and 9.5, respectively, at 380-500, 1000-1500 and 2000-2500 m asl, irrespective of land use practices. It indicated significant ($P = 0.01$) inverse correlation between altitude and crop diversity in control plots (without tree), AS and AHS system.

Compared to control, crop diversity was highest in agroforestry systems. Inter-comparing crop diversity between agroforestry systems, AHS system exhibited the highest crop diversity, followed by AS system. Among various altitudes, maximum crop diversity (30 spp.) was, however, recorded at 500-1000 m altitude in AHS system, followed by 380-500 m elevation (29 crop spp.) in the same agroforestry system. AHS system also had the maximum tree diversity compared to other agroforestry systems. On average, the tree diversity was 9.75, 6.6, 15.25 and 11.5, respectively, in AS, AH, AHS and SP system, irrespective of altitude. Whereas the average diversity was 12.0, 11.0 and 6.0, respectively, at 380-500, 1000-1500 and 2000-2500 m altitude, irrespective of

various agroforestry systems. Similar to crop diversity, there was significant inverse correlation (P = 0.01) between altitude and tree diversity in AS and AHS system.

On an average, four types of mixed crop compositions (MCC) have been recorded in rainfed agriculture across the elevational gradient, and as many as five crops (finger millet + cowpea + horse gram + soybean + amaranth or finger millet + cowpea + black gram + horse gram + soya bean) are grown in MCC.

A glance over the rainfed agricultural land was left fallow at each altitude after the cultivation of barnyard millet, paddy, finger millet, foxtail millet, and MCC2 (barley + lentil + mustard or barley + lentil or finger millet + amaranth + soyabean) and MCC3 (finger millet + cowpea + black gram or finger millet + cowpea + horse gram + soyabean + amaranth or finger millet + black gram + horse gram + cowpea + soybean). This is probably practiced to restore the soil fertility in the rainfed agro-ecosystem during the fallow period, *i.e.*, October to March (Semwal and Maikhuri, 1996; Singh, 1996; Semwal *et al.*, 2001). Singh (1996) has also reported that the farmers in Garhwal Hills maintain the crop diversity through their indigenous knowledge system. In Henwal valley of Garhwal Himalaya alone, the farmers maintain as many as 127 food providing plants which include 24 species of fruits, buds, flowers and seeds; 14 types of vegetables; 18 types of fruit species; 9 type of spices and condiments etc. The number of cereal/ millets and psedo-cereals being raised was 12, of pulses 10, and of oilseeds 8. Moreover, 15 different species of fodder are cultivated in or around agricultural fields. Thus, Himalayan food production system has been reported to be "food rich" from diversity point of view. Maikhuri *et al.* (1996) reported that a rich diversity of traditional crops occurs generally in the Himalaya and more particularly in Central Himalaya. Over 40 species of food grains are grown in traditional agroecosystems of Central Himalaya, which have been managed by the local farming communities since time immemorial.

However, during last 3-4 decades, there is fast decline in traditional crop diversity and many crops are facing danger of complete extinction and consequently the ecological and economic security of the traditional farming system of Garhwal Himalaya appears to be in jeopardy. Over the years, many of

the traditional varieties of crops, oilseeds and pulses have been replaced by artificially bred high yielding varieties. For example, China-4, Taichung, Govinda and Saket-7 high yielding rice varieties have replaced the traditional once. Similarly in wheat, traditional varieties have been replaced by a high yielding variety like Sonalika. This reduction in crop diversity is partly because of introduction of high yielding varieties and partly because of increased emphasis on cultivation of traditional cash crops (Maikhuri *et al.,* 1997a). Similar trend was observed in some other parts of Himalaya (Rao and Saxena, 1996).

In mountain agroecosystem, traditional crop diversity have a crucial role in maintaining the long term sustainability of the agricultural system as it enhance the productivity, minimize the risk of crop failure, improves soil fertility by incorporating legumes in the crop mixture, reduces the chances of pest, pathogen and weed infestations, conserves soil nutrients etc. The other characteristics of the traditional hill farming are that it is entirely based on the local resources. On the other hand, modern agriculture (introduction of high yielding varieties) operates based largely on external inputs.

Crop and Crop Byproduct Yield

Paddy (both, upland and lowland), barnyard millet, finger millet, amaranth, maize and pulses like cowpea, black gram, horse gram, soybean and kidney bean were the important summer crops of the region. Major winter crops include wheat, barley, pea, lentil and mustard. The average, paddy yield was recorded to be 26.1 and 14.3 q/ha, respectively, to lowland and upland paddy, irrespective of altitude and land use systems. Wheat productivity was noticed to be 24.2 q/ha in mono cropping and 18.5 q/ha in mixed cropping, irrespective of altitude. The data on crop yield proved that the paddy yield was at par with the national average of 19.13 q/ha, however, the wheat productivity was 12% less than the national average of 27.43 q/ha. Further the millet yield was also found at par with the national average yield. The average productivity of barley, finger millet, barnyard millet, maize and kidney bean was recorded to be 14.8, 11.4, 11.5, 17.3 and 17.2 q/ha, irrespective of altitude and land use systems. Other crops like mustard, pea, lentil, cowpea, black gram, horse gram and soya bean are

grown as mixed crops and the productivity was noticed to be 1.9, 2.63, 1.9, 3.56, 3.18, 2.33 and 2.74 q/ha, irrespective of altitude.

For all the crops, the productivity was higher in control plots (without tree) compared to agroforestry systems. The major crops like wheat, barley, maize, paddy, finger millet and barnyard millet, respectively, showed decrease in productivity by 9.6, 13.0, 28.5, 25.0, 32.0 and 34.0% in different agroforestry systems compared to control values. Similar trend was noticed in productivity of mustard, pea, pulses and amaranth etc. Interestingly, there was significant (P = 0.01) inverse correlation between altitude and crop yield of wheat, barley, mustard, pea, potato, onion, barnyard millet, finger millet, cowpea, black gram, paddy and kidney bean either in control plots or in different agroforestry systems.

The crop byproduct yield was 42.2, 24.41, 30.93, 31.0 and 32.5 q/ha, respectively, to wheat, barley, finger millet, paddy and barnyard millet. These crops mainly support the dry fodder requirement of livestock. Similar to grain yield, there was significant (P = 0.01) inverse correlation between altitude and crop byproduct yield of wheat, barley, barnyard millet, finger millet and paddy. Tree density also showed significant (P = 0.01) inverse correlation with yield of cereals/millets like wheat, barley, paddy, maize, barnyard millet and finger millet. Similar was the trend for tree density and crop yield of pulses, amaranth, potato and other vegetables.

In an earlier study, Toky *et al.* (1989a) also reported that crop yield declines in agroforestry systems of western Himalaya compared to open plots. For example, wheat productivity was recorded to be 21.2 q/ha in AS system. In case of present study, the wheat productivity was 20.85 q/ha. Similarly, economic yield of tomato (*Lycopersicum esculentum*), chilli (*Capsicum annuum*), rajmah (*Phaseolus vulgaris*), ginger (*Zingiber officinale*), pea (*Pisum sativum*) and potato (*Solanum tuberosum*) in AHS system in Western Himalaya was recorded to be 45.7, 36.0, 9.82, 8.1, 33.8 and 16.4 q/ha, respectively (Toky *et al.*, 1989a). In case of present study, the economic yield of the same crops was, respectively, 81.94, 22.8, 41.4, 40.7, 2.5 and 109.2 q/ha. These variations in the productivity might be due to various crop compositions, altitude, tree density/ha, quantity of FYM used etc. (Sundriyal *et al.*, 1994; Atul and Punam, 1996;

Dadhwal *et al.*, 1989; Bhatt and Chauhan, 2003; Maikhuri *et al.*, 1996; Nautiyal *et al.*, 1998; Singh, 1996 and Atul *et al., 1994*).

The crop productivity of major crops grown in Garhwal Himalaya has been found well with in the range as reported by Bhatt and Chauhan (2003) and Maikhuri *et al.* (1996). However, the productivity of paddy, soyabean, wheat, horse gram, pigeon pea and lentil recorded by Semwal and Maikhuri (1996) was comparatively higher than the productivity recorded in the present investigation. It might be due to the fact that the study was conducted in foothills where irrigation was assured and the high yielding varieties were introduced. In an another study, Punam (1989) recorded the maize yield of 21.3, 3.4 and 6.0 q/ha, respectively, in AS, AH and AHS agroforestry systems of Himachal Pradesh. In the similar study, the wheat productivity has been recorded as 21.12 q/ha in AS system. Sundriyal *et al.* (1994) has also recorded the yield of maize, rice, finger millet, wheat and barley, respectively, as 19.6, 8.2, 7.8, 10.3 and 14.1 q/ha in Sikkim Himalaya. Yield of other crops like black gram, horse gram, soyabean, potato and the fruit yield of orange (*Citrus reticulata*), guava (*Psidium guajava*), banana (*Musa paradisica*), lemon (*C. aurantifolia*), peach (*Prunus persica*), pear (*Pyrus communis*) and mango (*Mangifera indica*) was also well with in the range as recorded in the present investigations for the same crops. Thus, these studies support to the present findings.

The total requirements of cereal and millets, pulses and oils for Garhwal Himlaya have been calculated. Cereal and millets consumption for 3.47 million human populations has been calculated as 0.57 million-tonnes/yr against the projected production of 0.50 million tonnes indicating that the region is deficient by 12% in cereal and millet production. The total pulse production for the region was calculated as 0.0087 million tonnes against the requirement of 0.045 million tonnes. Accordingly the production of oil seed was 0.0087 million liters against the requirement of 0.0181 million liters/yr. Thus the region was found highly deficient (> 80%) in pulse and oil seed production.

Labour energy expenditure

In mountain villages of Garhwal Hills, there is hardly any scope for mechanized farming hence the agriculture is being operated by human labour and bullock power (Swarup, 1993). Bullock power is used for ploughing, leveling, hoeing/weeding, puddling and threshing. Rest of the operations is carried out by the human labour as detailed in results section. On an average, 1573.0 hrs of human labour and 120 hrs of bullock pair was required for one ha of cultivation, irrespective of altitudinal gradient and cropping pattern/crop rotation. There was significant inverse (P = 0.01) correlation between altitude and human labour and bullock power use to cultivate per ha of land. This might be due to the fact that with increasing altitudinal gradient, the fallow period was recorded for many crops. Inter-comparing human labour expenditure between summer and winter crops, it has been recorded that, winter crops require more human labour (1114.0 hrs/yr) compared to summer crops (1076.0 hrs/yr), irrespective of altitudinal variation for the same. Similarly, the bullock labour requirement was 92.5 and 74.0 hrs/yr, respectively, to winter and summer crops. For annual crops' cultivation, human and bullock labour use was 1184.0 and 88.15 hrs/ha/yr, irrespective of altitude and crops.

In an earlier study, Singh (1985) reported that a total of 1355 hrs of human labour was required to cultivate one ha of area with 692 hrs for winter and 663 hrs for summer crops, respectively. Similarly, Bullock hour requirement for one hectare of cultivation was 138.0 to 185.5, respectively, to summer and winter crops. In general, for Himalayan agroecosystems, Pathak and Singh (2000) reported that 854.3 hrs of human labour was required for one ha of cultivation. For Indian plain zone, Ravinrdranath *et al.* (1981) reported that on an average, 1039 hrs of human labour is required for one ha of paddy cultivation. Whereas in case of present study, the human labour requirement was 1337.2 hrs/ha. The bullock power requirement was 163 hrs in Indian plain zone for paddy cultivation compared to 115.6 hrs/ha in the hills. For Sikkim in Eastern Himalayas, Sundriyal *et al.* (1994) reported the human labour requirement of 1800, 1312, 960 and 3600 hrs/ha, respectively to rice, potato, maize and ginger cultivation. Similarly, the bullock labour requirement was 416, 280, 114 and 272

hrs/ha, accordingly to the same crops. It clearly indicates that comparatively more human labour is required for per ha of cultivation in the hills compared to plain zones of India. For Central Himalaya, Singh *et al.* (1992) reported that on an average, 1000 hrs of human labour and 320 hrs of bullock labour was needed for one ha of cultivation. Thus these findings seems in agreement with our observations for Garhwal Himalaya.

So far application of fertilizer was concerned, farmyard manure was found to be the main source of fertilizer at each altitude. Application of farmyard manure, however, varied based on the crop rotation and crop compositions *viz.* cultivation of MCC 1 (wheat + mustard + pea), followed by paddy showed the FYM consumption of 42.43 q/ha, whereas wheat followed by MCC 4 (maize + green gram) had the FYM consumption of 31.46 q/ha, followed by MCC 2 (barley + lentil + mustard) and sesame (30.0 q/ha). Among various crops, cultivation of millets required lowest FYM consumption (13.3 to 13.7 q/ha) whereas, cultivation of onion/garlic/potato followed by kidney bean had the highest consumption (44.65 q/ha). On an average, FYM consumption was 19.2 and 17.3 q/ha, respectively, to winter and summer crops, irrespective of altitude and crop composition.

Nautiyal *et al.* (1998) reported that the FYM application of 36.54 q/ha in home garden of mountain village of Garhwal Himalaya located at 700-1200 m asl. The similar study also showed that the 98% of the total energy input in simultaneous agroforestry as well as in home garden was from manure (FYM), which support to the present findings. However, the FYM application per ha of cultivation varied depending on the availability of the fodder resource, crop grown, distance of the agricultural fields from the village and livestock reared viz., in a study conducted by Bhatt and Chauhan (2003) in three villages of Garhwal Himalaya, the FYM application varied from 7.2-17.3 q/ha. Similarly Semwal and Maikhuri (1996) reported the FYM application of 47.3, 39.2 and 46.7 q/ha, respectively, in Jaidevpur, Dalimsain and Hathnur villages situated at 360-400, 800-900 and 1200-1400 m altitude in Garhwal Himalaya. Singh *et al.* (1992) also observed that on an average, 34.7 q of FYM is required for per ha cultivation in Central Himalayan agroecosystems, irrespective of crops grown. However, some of studies have proved very high rate of FYM application,

particularly in Eastern Himalaya. Sundriyal *et al.* (1994) recorded the FYM application of 55.0, 190.0 and 140.0 q/ha, respectively, to maize, ginger and potato cultivation in Sikkim Himalaya.

The characteristics feature of agriculture in Garhwal region is its organic base as more than 90% input was through FYM and only 10% was shared by human and bullock labour, seed etc. across an altitudinal gradient. From the foregoing discussion, it is also well understood that farmyard manure derived from the forest/ agroforestry and livestock components (consisting of dung, animal urine, bedding leaves and feed left-overs) contributed significantly more (> 90%) than any other input. Traditionally this was the main source of replenishing soil fertility after crop harvest, other source being crop rotations and fallowing (Swarup, 1993). On an average, the animal dung production for the region was projected to be 6.58 million tonnes/yr with dry matter content of 3.42 million tonnes. For cultivating 0.46 million ha, the projected requirement would be 1.963 million tonnes (@ 4.24 tonnes/ha of FYM).

Energy input (MJ/ha/yr) through human labour, bullock, FYM and seed was, respectively, 720.2, 740.2, 37231.0 and 1494.0. The total energy input was, therefore, 40185.4 MJ/ha/yr and FYM alone partitioned 90% input. Inter-comparing the energy input at different altitudes, low altitude (380-500 m asl) had highest energy input (43676.5 MJ/ha/yr) and lowest energy input was recorded at 1000-1500 m altitude (37327.5 MJ/ha/yr). Human and bullock labour showed significant (P = 0.01) inverse correlation with altitude, indicating that comparatively less human and bullock energy is needed with increasing altitude of the cropped area. No marked variations have been recorded in energy inputs in different agroforestry systems including control at each altitude. However, total energy input was highest in AHS system at each altitude, which was due to more application of FYM and seed rate. In all the agroforestry systems, significant (P = 0.01) inverse correlation was recorded between altitude and energy inputs.

The annual energy input presented in the thesis have been found well with in the range as reported by Nautiyal *et al.* (1998) for human, bullock labour and seeds; Bhatt and Chauhan (2003) for human labour, bullock power, FYM,

seed, and chemical & fertilizer; and Semwal and Maikhuri (1996) for human labour, bullock labour, FYM and seed in Garhwal Himalaya.

Energy output

Data on energy output for different crops along an altitudinal gradient indicated that grains, vegetables, spices, dry fodder from crops, grasses from terrace risers, tree fodder, fuelwood, and fruit contributed to total output in different systems. The average energy output was 147050 MJ/ha/yr, irrespective of altitude and land use system. Fruits contributed maximum energy (52064 MJ/ha/yr), followed by dry fodder yield from crops (41107 MJ/ha/yr), and grain/vegetable yield (37600 MJ/ha/yr). Inter-comparing energy output at different altitudes, low altitude (380-500 m) had highest energy output (166594 MJ/ha/yr). Lowest energy putput, however, was noticed for 1000-1500 m altitude (124422 MJ/ha/yr). The higher energy output at low altitude was due to the fact that area was not left fallow (except that of millets) and both, summer and winter crops are cultivated besides some intermediate crops. Whereas at other altitudes, most of the rainfed area is left fallow after cultivation of millets, paddy and barley in rainfed ecosystem. Correlation coefficient computed between energy output and altitude showed significant inverse ($P = 0.05$) correlation for grain/vegetable yield, crop biomass yield, firewood and fodder yield which indicates that with increasing elevational gradient the energy output decreases. However, there was significant ($P = 0.01$) positive correlation between altitude and fruit yield, which was due to the fact that fruit tree density was high in high altitude agroforestry systems.

The net energy return was recorded to be 106864 MJ/ha/yr, irrespective of altitude and land use system. Similar to total energy output, the net energy return was also highest at low altitude (122918 MJ/ha/yr). The energy output: input ratio was found to be 3.8, 3.3 and 4.1, respectively, at 380-500, 1000-1500 and 2000-2500 m altitude with average output: input ratio of 3.7, irrespective of altitude and land use systems. It has also been recorded that with increasing elevational gradient, the output: input ratio decreases in all the agroforestry systems including control. However, the net output: input ratio was higher (2.31-3.32) in agroforestry land use practice compared to control (2.23). On an

average, grain/vegetable yield, dry fodder, bund grass, tree fodder, firewood and fruit yield contributed respectively 25.6, 18.0, 0.30, 3.4, 7.3 and 35.4% to total net energy returns, irrespective of altitude and land use system.

Enormous works on energetics/ eco-energetics of hill agroecosystems have been carried out by various workers in different parts of the Himalaya (Pandey and Singh, 1984; Sharma, 1991; Ralhan *et al.*, 1992; Semwal and Maikhuri, 1996). Similar studies were done for land under shifting cultivation (*jhum*) in the northeastern hill region of Himalaya by Toky and Ramakrishnan (1981, 1982), Mishra and Ramakrishnan (1982), Maikhuri and Ramakrishnan (1990, 1991) and Ramakrishnan (1992). Most of the workers (particularly in Central Himalaya) have concentrated their efforts on those agroecosystems where generally common food crops, improved crop varieties and cash crops (vegetables) were grown. However, very little work has been undertaken in agroecosystems with traditional crops (Sharma, 1991; Negi, 1994; Singh, 1996; Makhuri *et al.*, 1997b). In the present investigation, an attempt has been made to record the ecoenergetic analysis of different agroforestry systems along an altitudinal gradient. It has been observed that total energy output was 95503.2, 114152.5, 124285.9 and 121494.0 Mj/ha/yr, respectively, in control, AS, AHS and AH system with net energy return of 56896.0, 80604.0, 70391.2 and 84445.6 Mj/ha/yr accordingly, in the same systems, irrespective of altitude and crop composition. It clearly indicates that the agroforestry systems have more energy efficiency compared to sole cropping. In an earlier study, Nautiyal *et al* (1998) also reported the total energy output of 193182.0, 54221.0 and 21000.0 Mj/ha/yr, respectively, in simultaneous agroforestry, sequential agroforestry system and home garden in mid altitude village of Garhwal Himalaya. Most of the traditional crops cultivated in higher Himalaya in mono or mixed cropping exhibited higher energy efficiencies than those grown at middle and lower altitudes. Similar observations have been made by Maikhuri *et al.* (1996) while reporting the energy efficiency of traditional crops grown in Central Himalaya across an altitudinal gradient. Enormous variation in energy efficiency reflected from the data is partly because of huge variation in structure and management within the broad category of traditional agroforestry systems and partly due to variation in methodology. For example, variety of crops were grown along the altitudinal gradient wherein the energy efficiencies varied significantly, however,

the data in the thesis has been shown on pooled basis, irrespective of crops and altitude. Similar variations in ecoenergetic analysis of Himalayan agroecosystems has been reported by Singh *et al.* (1997), Ralhan *et al.* (1992), Mishra and Ramakrishnan (1981), Negi and Singh (1990), Negi *et al.* (1989), Pandey and Singh (1984) and Ramakrishnan (1992). The energy output:input ratio was also found well with in the range as reported by Nautiyal *et al.* (1998), Bhatt and Chauhan (2003), Singh *et al.* (1997) and Pandey and Singh (1984) for Central Himalayan agroecosystems.

Monetary Efficiencies of Agroecosystems

The monetary input and output (Rs/ha/yr) for agriculture at different altitudes exhibited the total input of 16416.0, 15453.0, 14086.0 and 22481.0, respectively, to control AS, AH and AHS land use systems, irrespective of altitudinal variations. The details of the wages/rates for human labour, bullock labour, FYM, crops, and crop byproducts including fodder, fuel and fruit has been given in Tables 5 to 5.3. AHS land use system had the highest input in terms of currency. The average monetary input was Rs. 16615.0/ha/yr, and human labour, bullock labour, FYM and seed input, respectively, contributed 61.7, 13.8, 15.7 and 8.8% to total monetary input, irrespective of altitude and land use practice. The monetary input exhibited significant inverse correlation (P = 0.01) with altitude, which showed that the less monetary input is required at high altitude compared to low altitude. Among different components of monetary input, human and bullock labour showed the significant (P = 0.01) inverse correlation with altitude. The similar trend was also noticed in control and various agroforestry systems.

The perusal of data on monetary output indicated that AHS system is more remunerative compared to other land use practices. On an average, the total monetary output was 29434.0, 25428.0, 39506.0 and 76588.0 Rs/ha/yr, respectively, to control, AS, AH, AHS system, irrespective of altitude with net monetary return of Rs. 13018, 9975, 25420 and 54107.0/ha/yr, accordingly, to the same land use systems. Grain/vegetable, dry fodder, bund grass, tree fodder, firewood and fruit yield, respectively, contributed 45.6, 2.0, 0.2, 8.0, 1.8 and 44.0% to total monetary return. While significant (P = 0.01) inverse correlation between altitude and total monetary output and net return was

recorded in control and AS system, it was AH and AHS system, which showed significant (P = 0.01) positive correlation between altitude and net monetary output including net returns. Inter-comparing the net monetary returns at different altitudes, the high altitude (2000-2500 m) area had the highest output (Rs. 46056.0/ha/yr) with output: input ratio of 4.3, followed by 1500-2000 m altitude (net return = Rs. 41909/ha/yr, output: input ratio = 3.8). Among various altitudes, lowest monetary output: input ratio, however, was recorded at low (380-500 m) altitude, *i.e.* 2.81. It might be due to the fact that with increasing altitudinal gradient, farmers prefer to cultivate more fruit trees in or aroud agricultural fields compared to fuel/fodder trees. It also corroborates to the fact that many seasonal vegetables, spices, tuber crops along with fruit and promising multipurpose tree species are cultivated in agrihortisilvi system; they fetch comparatively better prices compared to cereal/millets grown in other systems.

Although there is no such other study to compare the data as in the present thesis the monetary input and output has been worked out along an elevational gradient for different agroforestry systems including control. However, some of the studies are available in relation to cost-benefit analysis of some agroforestry systems. For Central Himalaya, Gopinath (1999) recorded the net monetary output (Rs/ha/yr) of 26,097, 14,227 and 3,815, respectively, to traditional agroforestry systems in Pine and Oak region and agrihorticulture system. Among, various systems, AH agroforestry systems was found more remunerative compared to traditional systems. Singh *et al.* (1992) reported the net output of Rs. 26,320/ha/yr for Central Himalayan agroecosystems with net monetary benefit of Rs. 13,720/ha/yr. Nautiyal *et al.* (1998) observed the net monetary return of Rs. 15,703, 8,131 and 14,778/ha/yr, respectively, to simultaneous agroforestry, sequential agroforestry system and home garden with output: input ratio of 2.62, 7.82 and 5.32 accordingly, to the same agroforestry systems in Garhwal Himalaya.

Large variations in monetary output with net monetary return might be due to the fact that cropping pattern and crop composition varied with altitude besides tree species and their density. Further the prices of cereal/millet crops including pseudo-cereals were comparatively less than the cash crops like onion, garlic, potato, tomato, ginger, chilli and turmeric including horticultural trees like

mango (*Mangifera indica*), *Citrus* spp., pear (*Pyrus communis*), apple (*P. malus*), guava (P*sidium guajava)* and walnut (*Juglans regia*). It indicates that the monetary efficiency of the higher Himalayan agroecosystems was more compared to others. This finding is in conformity with the earlier observations of Maikhuri *et al.* (1996). The monetary output:input ratio mentioned in the present thesis are also well with in the range as reported by Gopinath (1999) and Singh *et al.* (1992) for Central Himalaya; Nautiyal *et al.* (1998) and Bhatt and Chauhan (2003) for Garhwal Himalaya; and Bhatt *et al.* (2000), Hmar *et al.* (2000), Mishra and Ramakrishnan (1982) for Eastern Himalayas.

EXECUTIVE SUMMARY

Although, various reports are available on structure and functioning of agroforestry systems of Kumaun Himalaya, but little work has been conducted on functioning of traditional agroforestry systems along altitudinal gradient in Kumaun Himalaya. **Therefore** the present investigation entitled "**Biomass consumption and assessment of cropping & yield patterns of various components under different traditional agroforestry systems, across an altitudinal gradient in Kumaun region of Central Himalayas**" was executed to cover the following aspects:

1. Identification of important agroforestry systems along an altitudinal gradient in Kumaun Himalaya.
2. Contribution of agroforestry trees in terms of fuel, fodder and fruit.
3. Assessment of cropping and yield pattern under different agroforestry systems across an altitudinal gradient in terms of energy and monetary as a currency.
4. Assessment of structure and functioning of agroforestry systems across an altitudinal gradient in Kumaun Himalaya.

The study site is located in the Kumaun region of the Central Himalaya. The Kumaun region is spread over a geographical area of 29698 Km^2 (29^0 24' to 30^0 28' N latitude and 69^0 48' to 80^0 6'E longitude). The study site is located in the Kumaun region of the Central Himalaya. To record the structure and functioning of traditional agroforestry practices, a preliminary survey was conducted across an altitudinal gradient (ranging for 380 to 2500 m asl). The entire study area was divided into 3 altitudinal zone viz 380 to 500 m asl; 1000 to 1500 m and 2000 to 2500 m. At each altitude, 3 villages were randomly selected for detailed studies. The sites differed in climatic conditions, land use patterns, socio-economic considerations etc. and each represents almost the entire area in which it is located.

Some major findings have been discussed herewith:

- Out of 0.46 million ha of gross cropped area in Kumaun Himalaya, agrisilvi (AS), agrihorti (AH) and agrihortisilvi (AHS) systems occupy, respectively, 0.102, 0.03 and 0.026 million ha. It indicates that AS, AH and AHS system represents, respectively, 22.2, 6.5 and 5.7% area of the total cultivated land. Similarly, out of 0.071 million ha of non-agricultural land, silvipastoral (SP) system was practiced over 14.1% of the area. Thus agroforestry was practiced over 0.159 million ha area, representing 29.8% area under tree based farming, irrespective of agroforestry systems.

- *Albizia lebbek, Boehmeria rugulosa, Celtis australis, Ficus* spp., *Grewia optiva, Morus* spp., *Ougeinia oojeinensis, Toona ciliata* and *Quercus leucotrichophora* etc has been found major multipurpose tree species in Garhwal Himalaya. The important fruit trees of the region were *Artocarpus heterophyllus, Carica papaya, Citrus* spp., *Juglans regia, Mangifera indica, Prunus* spp., *Pyrus* spp. and *Psidium guajava*.

- The tree density/ha of various multipurpose tree species in AS system was recorded as 150 and 136 respectively, at 380-500 and 1000-1500 m asl, irrespective of species. At species level, tree density in AS system was recorded highest to *Q. leucotrichophora* (27.24), followed by *G. optiva* (26.0) and *Mallotus philippenensis* (22.6), irrespective of altitude.

- In AH system, the tree density was 114.3, 124.9 and 117.0, respectively at 380-500, 1000-1500 and 2000-2500 m altitude, irrespective of species. Among various species, the tree density/ha was highest (42.6) to *Pyrus malus*, followed by *Citrus aurantifolia* (32.2), *C. sinensis* (31.3), *C. limonia* (25.3), *Musa paradisica* (21.8) and *P. communis* (21.7).

- In AHS system, the tree density/ha was 241.4 and 170.9 120.6, respectively, 380-500 and 1000-1500 m altitude. Among various species, tree density per ha was highest to *C. aurantifolia* (33.7), followed by *M. paradisica* (28.6) and *G. optiva* (20.8).

- In SP system, tree density/ha was found maximum at 380-500 m altitude (280.6 tree/ha), and among various species, tree density was highest to *G. optiva*, followed by *Melia azedarach* and *Bauhinia variegata*. Thus the tree density/ha was 132.3, 124.4, 208.2 and 249.4, respectively, in AS, AH, AHS and SP agroforestry systems, irrespective of altitude and species.

- Based on the IVI values, it has been observed that *G. optiva* was the dominant species up to 1000 m altitude being the IVI values 63.9 at 380-500 m altitude in AS system. At 1000-1500 m altitude, however, *C. australis* was the most dominating species being IVI values of 66.21 and 44.2, respectively, in AS and AHS system. *O. oojeinensis* and *G. optiva*, respectively, ranked second and third at this altitude in dominance. Beyond 1500 m altitude, *Q. leucotrichophora* followed by *C. australis* and *G. optiva* were the most dominating species.

- In silvipastoral system, 15 tree species were found up to 1000m altitude. Among various species, *Dalbergia sissoo* and *Grewia optiva* were the most dominating, at 380-500 m altitude being the IVI values 57.14 to the same species.

- So far IVI of important horticultural species was concerned, *Citrus aurantifolia* was the most dominating species in AH system at 380-500 m altitude ~~being~~ having the IVI value of 83.7. On the other hand, beyond 2000 m altitude, *Pyrus malus*, followed by *P. communis* and *Juglans regia* were the most dominating species having IVI values of 140.01, 63.71 and 29.2, respectively.

- Tree fodder yield was recorded as 19.04, 10.74 and 26.1 q/ha/yr, respectively, in AS, AHS and SP systems. Similarly, the firewood yield was recorded to be 9.60, 5.21 and 12.1 q/ha/yr, respectively, from the same systems. The fibre yield was 0.10, 0.06 and 0.19 q/ha/yr from AS, AHS and SP systems, irrespective of altitude, and the average fruit yield was 36.17 and 27.41 q/ha/yr, respectively, from AH and AHS systems, irrespective of altitude.

- Among various altitudes, fodder and fuelwood yield was highest at 1000 to 1500 m altitude being the average value of 21.70 and 11.81 q/ha/yr, respectively. Fruit yield was maximum (58.45 q/ha/yr) at 2000 to 2500 m altitude in AH system.

- At species level, *Boehmeria rugulosa, Celtis australis, Grewia optiva, Ficus auriculata, Melia azedarach, Ougeinia oojeinensis* and *Morus alba* exhibited the highest fodder yield, irrespective of altitude. The fuelwood yield was 1.17, 1.62, 1.50, 0.35, 1.17, 1.26 and 1.08 q/ha/yr, accordingly to the same species.

- Among fruit trees, maximum fruit yield was recorded for *Pyrus malus, Citrus sinensis* and *Pyrus communis* being the yield values of 16.56, 8.97 and 8.55 q/ha/yr, respectively, irrespective of altitude and land use systems.

- So far fodder production was concerned, it has been recorded that the gross cropped area (*i.e.*, 0.46 million ha) and non-agricultural land (0.071 million ha) could produce 0.29 million tonnes of green fodder and 1.80 million tonnes dry fodder. Thus, agriculture of the region fulfills, respectively, 2.0 and 53% requirement of green and dry fodder including the fodder production from different agroforestry systems.

- The average firewood consumption was 1.07, 1.42 and 2.80 kg/capita/day, respectively, at 380-500, 1000-1500 and 2000-2500m altitude. On an average, 1.7 million tonnes of firewood was required per annum to meet out the energy requirements of rural folk of Kumaun Himalaya. The firewood production from different agroforestry systems has been recorded as 0.22 million tonne/yr. It indicated that agroforestry helped to supplement 13% of the total firewood requirement of rural populace.

- Crop diversity was highest in agroforestry systems. Inter-comparing crop diversity between agroforestry systems, AHS system exhibited the highest crop diversity, followed by AS system. Among various altitudes, maximum crop diversity (29 spp.) was, however, recorded at 380-500 m altitude in AHS system. AHS system also had the maximum tree diversity compared to other agroforestry systems. Whereas the average diversity was 12.0, 11.0 and 6.0, respectively, at 380-500, 1000-1500 and 2000-2500 m altitude, irrespective of agroforestry systems. Crop and tree diversity showed significant inverse correlation ($P = 0.01$) with altitude.

- For all the crops, the productivity was higher in control plots (without tree) compared to agroforestry systems. The major crops like wheat, barley, maize, paddy, finger millet and barnyard millet, respectively, showed decrease in productivity by 9.6, 13.0, 28.5, 25.0, 32.0 and 34.0% in different agroforestry systems compared to control. Similar trend was noticed in productivity of mustard, pea, pulses and amaranth.

- The average paddy yield was recorded to be 26.1 and 14.3 q/ha, respectively, to lowland and upland paddy, irrespective of altitude and land use systems. Wheat productivity was noticed to be 24.2 q/ha in mono cropping and 18.5 q/ha in mixed cropping, irrespective of altitude. The data on crop yield proved that the paddy yield was at par with the national average of 19.13 q/ha,

however, the wheat productivity was 12% less than the national average of 27.43 q/ha.

- The average productivity of other crops like barley, finger millet, barnyard millet, maize and kidney bean was recorded as 14.8, 11.4, 11.5, 17.3 and 17.2 q/ha, irrespective of altitude and land use systems. Other crops like mustard, pea, lentil, cowpea, black gram, horse gram and soyabean were grown as mixed crops and the productivity was estimated as 1.9, 2.63, 1.9, 3.56, 3.18, 2.33 and 2.74 q/ha, respectively, to the same crops, irrespective of altitude. Significant (P = 0.01) inverse correlation between altitude and crop yield of wheat, barley, mustard, pea, potato, onion, barnyard millet, finger millet, cowpea, black gram, paddy and kidney bean was recorded either in control plots or in different agroforestry systems.

- The crop byproduct yield was 42.2, 24.41, 30.93, 31.0 and 32.5 q/ha, respectively, to wheat, barley, finger millet, paddy and barnyard millet. There was significant (P = 0.01) inverse correlation between altitude and crop byproduct yield of wheat, barley, barnyard millet, finger millet and paddy. Tree density also showed significant (P = 0.01) inverse correlation with yield of cereals/millets like wheat, barley, paddy, maize, barnyard millet and finger millet. Similar was the trend for tree density and crop yield of pulses, amaranth, potato and other vegetables.

- On an average, 1573.0 hrs of human labour and 120 hrs of bullock labour was required for one ha of cultivation, irrespective of altitudinal variations and cropping pattern/crop rotation. Altitude showed significant inverse (P = 0.01) correlation with human labour and bullock power use. Winter crops required more human labour (1114.0 hrs/yr) compared to summer crops (1076.0 hrs/yr), irrespective of altitudinal variations. Similarly, the bullock labour requirement was 92.5 and 74.0 hrs/yr, respectively, to winter and summer crops. For annual crops' cultivation, human and bullock labour use was 1184.0 and 88.15 hrs/ha/yr, irrespective of altitude and crops.

- Organic base seemed the characteristic feature of agriculture in Kumaun region. At since these was 90% input only through farmyard manure (FYM) at each altitude. Rest was shared by human and bullock labour and seed etc. Application of farmyard manure, however, varied based on the crop rotation and crop compositions *viz.* cultivation of MCC 1 (wheat + mustard + pea), followed by paddy showed the FYM consumption of 42.43 q/ha, whereas wheat followed by MCC 4 (maize + green gram) had the FYM consumption of 31.46 q/ha, followed by MCC 2 (barley + lentil + mustard) and sesame (30.0 q/ha). Among various crops, cultivation of millets required lowest FYM consumption (13.3 to 13.7 q/ha) whereas, cultivation of onion/garlic/potato followed by kidney bean had the highest consumption (44.65 q/ha). The average FYM consumption was 19.2 and 17.3 q/ha, respectively, to winter and summer crops, irrespective of altitude and crop composition.

- Energy input (MJ/ha/yr) through human labour, bullock, FYM and seed was, respectively, 720.2, 740.2, 37231.0 and 1494.0. The total energy input was, therefore, 40185.4 MJ/ha/yr. Low altitude (380-500 m asl) had highest energy input (43676.5 MJ/ha/yr) whereas, lowest energy input was recorded at 1000-

1500 m altitude (37327.5 MJ/ha/yr). Human and bullock labour showed significant (P = 0.01) inverse correlation with altitude.

- In general, agroforestry systems had more energy efficiency compared to sole cropping. The average energy output was 147050 MJ/ha/yr, irrespective of altitude and land use system. Fruits contributed maximum energy (52064 MJ/ha/yr), followed by dry fodder yield from crops (41107 MJ/ha/yr) and grain/vegetable yield (37600 MJ/ha/yr). Inter-comparing energy output at different altitudes, low altitude (380-500 m) had highest energy output (166594 MJ/ha/yr). Lowest energy output, however, was noticed for 1000-1500 m altitude (124422 MJ/ha/yr).

- Correlation coefficient computed between energy output and altitude showed significant inverse (P = 0.05) correlation for grain/vegetable yield, crop biomass yield, firewood and fodder yield. However, there was significant (P = 0.01) positive correlation between altitude and fruit yield.

- The energy output: input ratio was found to be 3.8, 3.3 and 3.4 respectively, at 380-500, 1000-1500 and 2000-2500 m altitude with average output: input ratio of 3.7, irrespective of altitude and land use systems. It has also been recorded that with increasing elevational gradient, the output: input ratio decreases in all the agroforestry systems including control. However, the net output: input ratio was higher (2.31-3.32) in agroforestry land use practice compared to control (2.23).

- The monetary input and output (Rs/ha/yr) for agriculture at different altitudes exhibited the total input of 16,416.0, 15,453.0, 14,086.0 and 22,481.0, respectively, to control, AS, AH and AHS land use systems, irrespective of altitudinal variations. The monetary input exhibited significant inverse correlation (P = 0.01) with altitude.

- The perusal of data on monetary output indicated that AHS system was more remunerative compared to other land use practices. On an average, the total monetary output was 29,434.0, 25,428.0, 39,506.0 and 76,588.0 Rs/ha/yr, respectively, to control, AS, AH, AHS system, irrespective of altitude with net monetary return of Rs. 13,018, 9,975, 25,420 and 54,107.0/ha/yr, accordingly, to the same land use systems. Grain/vegetable, dry fodder, bund grass, tree fodder, firewood and fruit yield, respectively, contributed 45.6, 2.0, 0.2, 8.0, 1.8 and 44.0% to total monetary return.

- While significant (P = 0.01) inverse correlation between altitude and total monetary output and net return was recorded in control and AS system, it was AH and AHS system, which showed significant (P = 0.01) positive correlation between altitude and net monetary output including net returns.

- Inter-comparing the net monetary returns at different altitudes, the high altitude (2000-2500 m) area had the highest output (Rs. 46056.0/ha/yr) with output: input ratio of 4.3. Among various altitudes, lowest monetary output: input ratio, however, was recorded at low (380-500 m) altitude, *i.e.*, 2.81.

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*Originals not seen